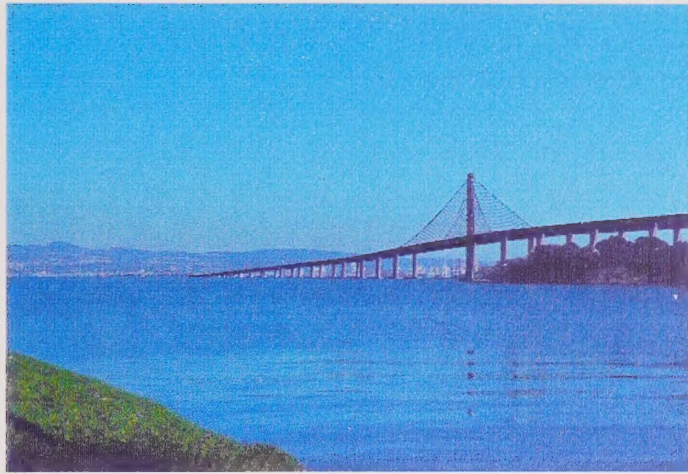


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BAY BRIDGE RAIL FEASIBILITY STUDY



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EXECUTIVE SUMMARY

For more than sixty years, the San Francisco-Oakland Bay Bridge has been one of the landmarks most identified with the Bay Area. During that time, the bridge has undergone several modifications. Originally designed with five lanes of auto traffic on the top deck, and commercial vehicles and "Key System" rail on the lower deck, the bridge was converted to ten lanes of auto operations (five in each direction) in 1959.

Although the bridge is thought of as a unit, structurally it is actually two distinct bridges that meet at the Yerba Buena Island (YBI) tunnels. The West spans include the graceful suspension sections connecting YBI to the San Francisco anchorage. The East spans connect YBI to Oakland, utilizing a cantilever system.

Following the 1989 Loma Prieta earthquake, which resulted in a failure of the upper deck and a month-long closure of the bridge, Caltrans conducted an extensive assessment of the options for seismic strengthening of the Bridge. Their studies concluded that it was possible and cost effective to strengthen the West spans, while the East spans required full replacement. Strengthening of the West spans is already underway. East span design is progressing and the entire seismic strengthening project will be completed over the next decade.

In 1998, voters in four cities - Oakland, Berkeley, Emeryville and San Francisco - passed a non-binding declaration of policy stating that rail service should be restored to the Bay Bridge. The ballot measure that was placed on the four city ballots did not define what type of rail service would be offered, where it would go, or what it would cost to complete. The Metropolitan Transportation Commission (MTC) sponsored this feasibility study as a first step towards narrowing the question of how or whether to implement rail on the bridge. The study is designed to answer three key questions:

- **What are the possible options for rail service on the Bay Bridge?** This includes defining technology options and alignment possibilities for rail service, both over the bridge span, and within the west and east bay areas.
- **What are the impacts of each type of rail service on the structure of the Bay Bridge?** This requires an understanding of where the rails might be located, whether they would change the lane configuration on the bridge, and how the east and West span systems will be joined by rail.
- **How much will the structural changes and the rail infrastructure cost to implement?** While this feasibility level study is done without any engineering or design work, it does provide an order of magnitude estimate of costs, both for structural improvements and for the rail infrastructure itself. It should be noted that not all costs need to be incurred at the same time - for example, it is possible to add the rails to the bridge before adding the rail infrastructure for a long term implementation.

For the purposes of this study, the seismically retrofitted West spans and the proposed replaced East spans were considered.

RAIL OPTIONS

Four rail options were identified, each providing service to a different but significant share of the travel market:

- Transbay Light Rail Service
- BART Transbay Bridge Service
- Basic Bridge Railroad Service - combining commuter rail and high speed rail
- Aggressive Bridge Railroad Service - combining commuter rail and high speed rail

Figures describing these alternatives are attached at the end of this Executive Summary.

Transbay Light Rail Service

This would be a modern version of the Key System, characterized by operation from the Transbay Terminal, where space would be shared with transbay buses on the bus deck, over the Bridge to the East Bay where service would divide into three routes, providing frequent all-day service. The three routes assumed in this study included an Oakland-Foothill Blvd. - Airport route; a MacArthur-Hegenberger route; and a Berkeley-Telegraph-University route.

BART Transbay Bridge Service

Significant additional transbay BART service could be offered by taking one of the four present transbay lines out of the Transbay tube and placing it on the Bridge. For purposes of this study, it was assumed that the Richmond-San Francisco line would run over the bridge. New aerial structure would be required to connect the bridge line to the MacArthur station. Service on this line would be improved and service to the remaining tube lines would also be improved to take advantage of the capacity that would become available in the tube.

Basic Railroad Service

This alternative would add both FRA compliant commuter rail and high speed trains over the Bay Bridge. Trains would be operated up the Peninsula, through Downtown San Francisco's Transbay Terminal and over the Bay Bridge. All transbay trains would stop at a new Oakland Harbor Station. From there, half of the trains would head north, stopping at Emeryville, West Berkeley and on to Richmond. From Richmond, some trains could be extended as part of the Capitol Corridor, by connecting to diesel powered Sacramento-Oakland-San Jose trains. The remaining trains would turn south and run along a new track, stopping at 16th Street, running

along Third street to Broadway and Oak where they will terminate. Commuter service would be supplemented by high speed rail operating as far as the Oakland Harbor Station.

Although high speed service is assumed to travel over the bridge, none of the rail services would be traveling at high speeds over the bridge, particularly over the West spans. The probable alignments and grades entering and exiting the Transbay Terminal will require operating speeds appropriately below the speeds along unencumbered portions of the alignment. Due to vertical and horizontal geometric restrictions, the operating speeds are assumed to be roughly 50 miles per hour.

Aggressive Rail Service

A more aggressive rail option would extend the commuter and high speed services beyond the area described under the basic scenario, and would also improve frequency of service. Trains turning north would continue to Martinez, with half of the trains continuing further to Suisun-Fairfield. Some trains would be extended to Sacramento. High speed trains would operate over the bridge every 30 minutes, with every other train going on to Sacramento. The southern commuter rail line would be extended to San Jose.

IMPACTS OF RAIL SERVICE ON THE BAY BRIDGE

Each of these rail options has a different impact on the bridge structure. Figure ES-1 shows the rail system weight and clearance requirements for each option.

FIGURE ES-1
RAIL SYSTEM WEIGHT AND CLEARANCE DATA

Rail System	Loaded Rail Car Weight in lbs. per linear foot of track	Rough Rail Envelope Size (height by width)	
		Single Track	Double Track
BART	1,170	14' by 16'	14' by 32'
Light Rail	1,390	18' by 16'	18' by 29'
SEPTA	1,720	26' by 17'	26' by 34'
Amtrak – Acela (high speed)	1,800	26' by 17'	26' by 34'
Caltrain – Current System*	1,900	26' by 17'	26' by 34'

*Included as a basis of comparison.

Summary of West Span Impacts

Adding rail to the West spans can be achieved in any of three configurations: either below the existing deck, alongside the upper deck, or alongside the lower deck. Under any of these options either rail operations or auto lanes can be placed outside of the current bridge envelope, providing the widest range of alternative locations for rail. Each of these options has advantages and constraints. From a rail operations perspective, rail suspended below the current lower deck of the bridge has the advantage of working best with the concept for an underground Transbay Rail Terminal. Rail placed alongside either of the existing spans, outside of the envelope of the current structure is not compatible with an underground terminal. Placing rail below the current lower deck has a potential flaw however, in that it will reduce the vertical clearance of the maritime channel, requiring Coast Guard approval. Another possible alternative, replacing auto lanes with rail service was not considered, as increasing demand for Transbay travel will necessitate expanding capacity for all modes. Total travel in the Transbay corridor is expected to increase by 22% over the next 20 years from 518,000 person trips in 2000 to 633,400 daily person trips in 2020.

While each of the alternatives for rail implementation is highly complex, none is considered infeasible. The added weight from either the side-by-side or below deck schemes would require improvements to the foundations, strengthening of the existing truss and towers, and possibly the replacement of the current concrete roadway decks with a much lighter system. Even with the implementation of a lighter decking system, strengthening of the main cable is anticipated. The main cable system would need to be strengthened by adding two new main suspension cables above or beside the existing cables or by adding new tower legs at the existing pier locations and suspending cables from these. This amounts to essentially building a new bridge on the outside of the existing bridge.

Adding weight for rails and for the structural improvements required will impact seismic behavior. Seismic improvements beyond those envisioned for the current retrofit would be necessary and would likely include foundation strengthening as well as pier, truss and tower strengthening.

Summary of East Span Impacts

A review of the current design of the replacement span suggests that the bridge is designed for five traffic lanes in each direction with the potential to add one lane of rail and carry four traffic lanes in each direction. While there is sufficient width for five lanes of traffic and rail in each direction, the design lacks the structural strength to carry this load.

The current design places rail on the insides of the two parallel decks. This alignment does not provide the greatest flexibility for crossing YBI and connecting to the West spans. Moving rails to the outside of the decks would provide the needed flexibility, allowing for new tunnel bores to be constructed without impacting current traffic operations.

To accommodate any of the proposed rail options on the East spans, the design team currently completing this work would need to be redirected to fully incorporate the needs of rail into the design. While this would add to the cost of the East span, and could introduce some additional delay in the project, it would be less costly to make these changes during design and initial construction, rather than waiting until after the bridge is built.

Summary of Yerba Buena Island Impacts

The feasibility study showed that reconstruction of the existing YBI tunnel is not feasible without closing the bridge for sustained periods. Reconstruction would be necessary unless new bores are created, because of headroom and load carrying constraints. Therefore, construction of new tunnel bores is considered the preferred alternative for crossing the island.

COSTS

Costs were determined by the study team working closely with a peer panel, using national and international examples of recent costs. Unit costs for any project on the Bay Bridge would be higher than most projects because of the unique environment, working on an older structure, and the need for continual traffic operations. Figure ES-2 summarizes the costs for Bay Bridge structural improvements only. It should be noted that these are feasibility level costs only, and will be considerably refined with more study. The structural costs for Bay Bridge improvements are estimated at about \$3 Billion, regardless of the technology selected.

FIGURE ES-2
STRUCTURAL COST SUMMARY

	Options	
	Below	Side by Side
San Francisco Approaches	\$193	\$436
West Spans	\$1,334	\$1,447
Yerba Buena Island	\$317	\$198
East Spans*	\$546	\$546
Oakland Mole	\$60	\$40
Subtotal	\$2,450	\$2,667
25% Contingency	\$612	\$667
Total	\$3,062	\$3,333

Costs are in Millions

* East span costs are based on revisions to the design prior to awarding the construction contract. Costs to implement heavy commuter rail would be higher if widening and strengthening were performed after construction.

The costs estimated in Figure ES-2 provide a "rail ready bridge". The true cost of implementing rail service includes the cost of rail infrastructure and rolling stock as well as the costs of bridge modifications. Figure ES-3 summarizes the costs of each of the four alternatives considered, exclusive of the bridge costs. Costs range from about \$1 Billion to as much as over \$4 Billion. It should be noted that any rail option could be completed in stages, avoiding the need to spend the full costs at once.

FIGURE ES-3
ALTERNATIVE COST SUMMARY
 (1999 \$)

Alternative	Infrastructure*	Rolling Stock	Total
A. Transbay Light Rail Service	\$1.4 billion	\$210 - \$315 million	\$1.6 - 1.8 billion
B. BART Transbay Bridge Service	\$1.8 billion	\$144 million	\$1.94 billion
C. Basic Bridge Railroad Service	\$774 million	\$144 million	\$918 million
D. Aggressive Bridge Railroad Service	\$4.3 billion	\$461 million	\$4.77 billion

*Infrastructure includes all estimated project contingency (40%) and engineering (30%), including that applied to rolling stock.

The total capital costs for Transbay rail service using the Bay Bridge would range from about \$5 Billion to as much as \$9 Billion. Costs to operate rail service would be in addition to capital costs and would require substantial annual operating subsidies.

NEXT STEPS

While implementing Transbay Rail service is feasible, it represents an enormous investment. Still, the ultimate benefits of such an investment can not be known at this time. The costs and benefits of this option must also be compared to other potential investments.

To better understand the relative value of this investment, a more inclusive corridor study is required. This study would complete similar feasibility level analyses of various options including implementing a busway, adding an additional bridge (either as a rail bridge, or as a traffic reliever, making it possible to displace traffic with rail on the existing bridge), or adding a new transbay rail tube. Only when this option can be put into context with other alternatives will the benefits of Bay Bridge rail service be known. Following that study, much more detailed work is required to refine the cost estimates and alignments proposed in this feasibility study.

MTC has initiated the process for a San Francisco Bay Crossing study that will expand on the conclusions of this preliminary study. The Bay Crossing study will consider:

- improvements to existing bridges with or without rail service
- adding a new rail tube for commuter and high speed rail services
- adding a second BART tube for increased Transbay service
- expanded ferry options
- bus service and busway options

- other operational enhancements to improve Transbay capacity

CHAPTER 1. INTRODUCTION

BAY BRIDGE HISTORY

The longest bridge in the world at the time of its construction, the 1936 opening saw the Bay Bridge carrying 6 lanes of passenger vehicles on the upper deck and three lanes of trucks and two tracks of rail on the lower deck as shown in Figure 1-1. The rail system, known as the "Key System" was ultimately replaced by rubber tire buses. Under the increasing pressure for vehicular capacity, the bridge was converted by 1963 from a mixed use bridge to one accommodating vehicle traffic only. The conversion removed all of the rail systems and replaced the lower deck with a precast concrete slab.

During this conversion, the tunnel at Yerba Buena Island was reconfigured, removing the lower level wall between the rail and roadway that supported the upper level deck, requiring the upper deck to span the bridge without intermediate support.

Although traffic on the bridge has increased dramatically, live structural loads have not increased over time. In fact, the removal of trains actually reduced live load requirements.

Between 1963 and 1988, the Bay Bridge was not seismically changed. Following the Loma Prieta earthquake, Caltrans began a study of alternatives for seismic strengthening of the bridge structure. After a number of years of study, Caltrans has developed a plan for seismic retrofit of the west suspension spans of the bridge, between Yerba Buena Island and San Francisco, and replacement of the East span, between the Island and Oakland. Retrofit and replacement activity is already underway and will be completed by 2010.

STUDY PARAMETERS

As a feasibility study, the intention is to provide knowledgeable judgements as to the structural and economic possibilities of placing rail on the bridge. The work within this context is very "broad-brush." In the sequence of engineering work to follow this feasibility study, the next level of effort would be preliminary design followed by final design. Each step takes the design and cost estimates to the next level of detail and accuracy.

Limitations, therefore, do exist within this study. First, computer modeling was not undertaken. Short of a rigorous, three-dimensional, non-linear computer analysis, any lesser effort would provide only partial answers. Such preliminary answers are more readily obtained through existing calculations.

FIGURE 1-1
RAIL ON THE WEST SPANS IN 1959



Courtesy of Caltrans

Lane load assumptions were derived from a 1965/67 Caltrans study that placed the live load from all 10 lanes in varying arrangements along the entire span. For this study, the West span's structural demands under proposed lane and rail roads are established by proportioning the 1965/67 values. Such proportioning implies that the proposed train may extend the full span length of the bridge. Since actual train lengths are much less than the bridge span, the demands on some structural components will be reported higher than actual impacts.

Calculations for the East spans are currently underway and will not be available prior to the completion of this study. Proportioning similar to the West span work will not be possible. The basis for assessment of the East spans will be strictly based on the design criteria.

These qualifiers are meant to place this study into context. Suspension bridges are simple in form yet complex to analyze. That complexity is expanded when seismic performance is studied. Such detailed work would be undertaken in a preliminary design effort that would follow this completed feasibility study.

CHAPTER 2. RAIL SERVICE OPTIONS

The feasibility of rail on the Bay Bridge depends largely on the type of rail service that is implemented. For this feasibility study, four rail technology options were studied. It should be noted that the implementation of any service option would depend on the demand for service and the availability of operating funds. No detailed study of demand or patronage was completed for this study; however, previous studies and the MTC Blueprint suggest that a significant market could be served by any of these options. The options included in the Rail Feasibility Study were:

- **Alternative A – Transbay Light Rail Service**
- **Alternative B – BART Transbay Bridge Service**
- **Alternative C – Basic Bridge Railroad Passenger Service**
- **Alternative D – Aggressive Bridge Railroad Passenger Service**

Alternatives C and D both include the commuter rail and high speed technologies. A more detailed discussion of the infrastructure requirements and capital costs of each alternative is presented in Chapter 5 of this report.

ALTERNATIVE A – BAY BRIDGE LIGHT RAIL

This would be a modern version of the Key System, characterized by operation from the Transbay Terminal, where space would be shared with transbay buses on the bus deck, over the Bridge to the East Bay where the service would divide into several main transbay trunk routes offering frequent all-day service. In the East Bay, trains of up to three cars would operate primarily at grade in city streets, employing a variety of traffic and transit-priority treatments. Selective grade separations might also be used, as required. Low-floor, high-performance rolling stock would be used. An example of the rolling stock used for this type of service is seen on Figure 2-1.

FIGURE 2-1
PORTLAND TYPE 2 LOW-FLOOR LRV



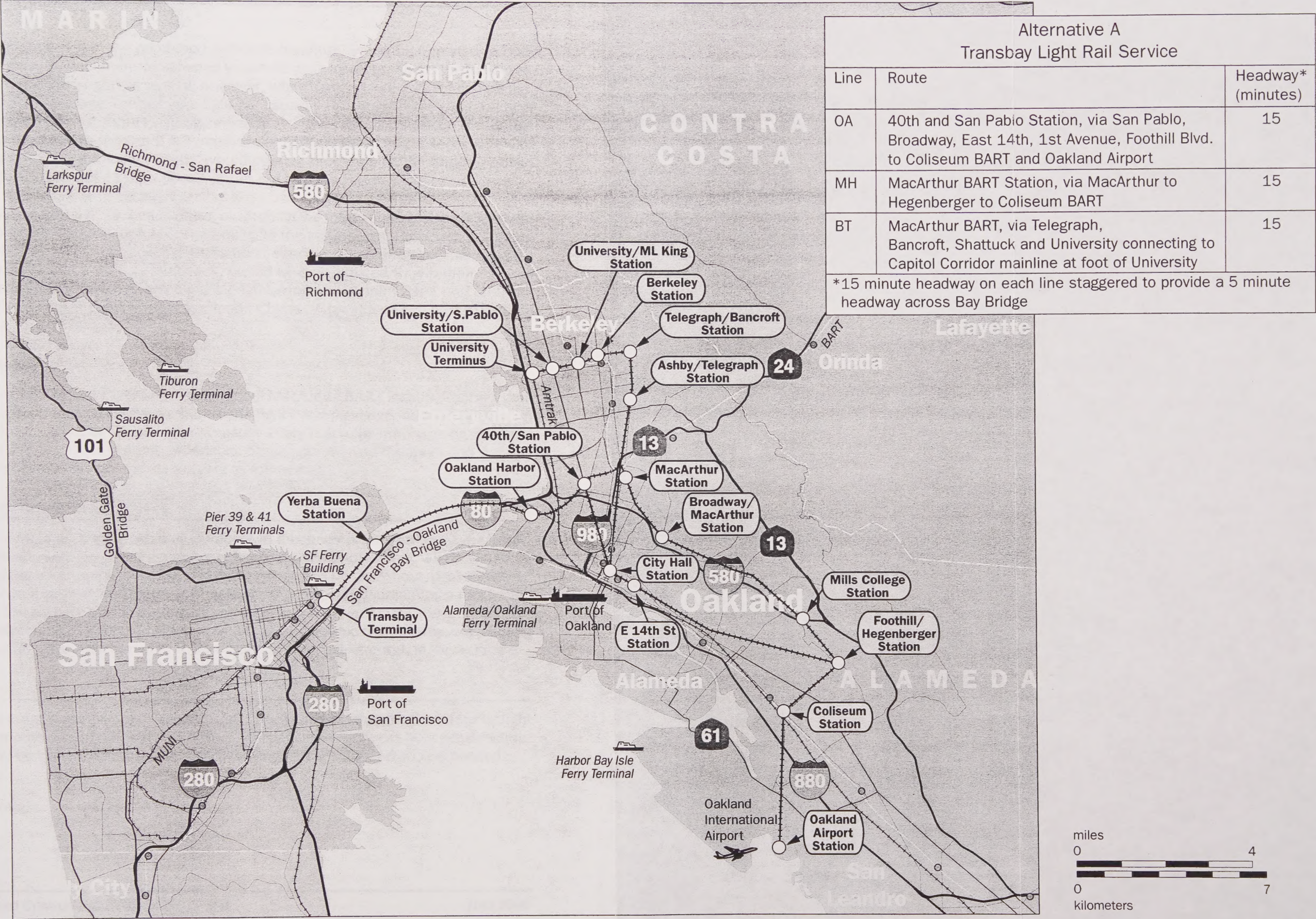
Route Concept

In this alternative, three illustrative light rail lines would provide Transbay Service from the Transbay Terminal to the East Bay (see Figure 2-2). Each would operate on a 15-minute headway, with evenly staggered timetables providing a uniform 5-minute headway between San Francisco and proposed "Oakland Harbor Station", to be located east of the Toll Plaza. These lines would complement and extend the reach of the BART system through a seamless service and fare structure.

- Oakland-Foothill Blvd- Airport (designated "OA" below): from 40th via San Pablo, Broadway, East 14th, 1st Avenue, Foothill Blvd., Hegenberger, via Coliseum BART to Airport.
- MacArthur-Hegenberger (designated "MH" below): via MacArthur BART, MacArthur to Hegenberger, then to a terminal at Coliseum BART.
- Berkeley-Telegraph-University (designated "BT" below): from MacArthur BART via Telegraph, Bancroft, Shattuck, and University to the Union Pacific mainline.

Figure 2-2

Bay Bridge Alternatives Study, Alternative A - Light Rail Service Alignment



An initial assumption is that the combined 5-minute headway would be operated in both peak and base periods, with trains lengthened to handle peak loadings. This is the most cost-effective way to operate a light rail service; however, when demand forecasts are completed, a balancing of the patronage forecast with light rail capacity may suggest the desirability of providing more trains on a shorter aggregate headway. (The signal system on the Bridge could permit a headway as short as 2 1/2 minutes, or perhaps less if found necessary). For working purposes, it is assumed that trains would operate at 50 mph on the Bridge, with an average scheduled speed of 15 mph (four minutes per mile) in East Bay streets.

This would require a total of 36.3 track miles, over which the three routes totaling 56.1 route miles would operate. The conceptual cost estimate for this system's infrastructure, excluding light rail vehicles, but including track, signals, stations, structures, electrification, maintenance facility, engineering and a 40% contingency, would be an estimated \$1.4 billion. This is based, as noted elsewhere, on essentially 0% engineering at this point. The unit costs are based primarily on recent experience in Portland. Chapter 5 provides more background on this conceptual cost development.

Running Times

As noted above, trains would average 15 mph east of MacArthur BART Station. Running time on the Bay Bridge would be similar to that for the BART and passenger railroad options. In the East Bay, stops would be spaced approximately every half mile, emphasizing access to BART stations and key off-line traffic generators. Some approximate distances and running times between illustrative light rail stations are as follows:

Rolling Stock Assumptions

The light rail vehicle used for illustrative purposes in this study is the Portland Type 2 low-floor car. Estimates were prepared assuming either two or three-car trains, which would be associated with an hourly capacity of 3000 to 4500 passengers per peak hour, peak direction. Seventy cars would be provided for the former capacity, and one hundred fifteen cars for the latter. This is the primary reason for the cost range given in the summary above, but there would be an effect from a larger maintenance facility and associated right-of-way, engineering and contingencies. See Attachment A in Section 6 for more background on this estimate.

Capacity

Depending on train length (two or three cars), the capacity delivered across the bridge by light rail in this alternative would range from 3,000 - 4,500 passengers per peak hour per direction. The line would be signalized for shorter headway, higher capacity operation if needed.

FIGURE 2-3
TRANSBAY LRT RUNNING TIMES

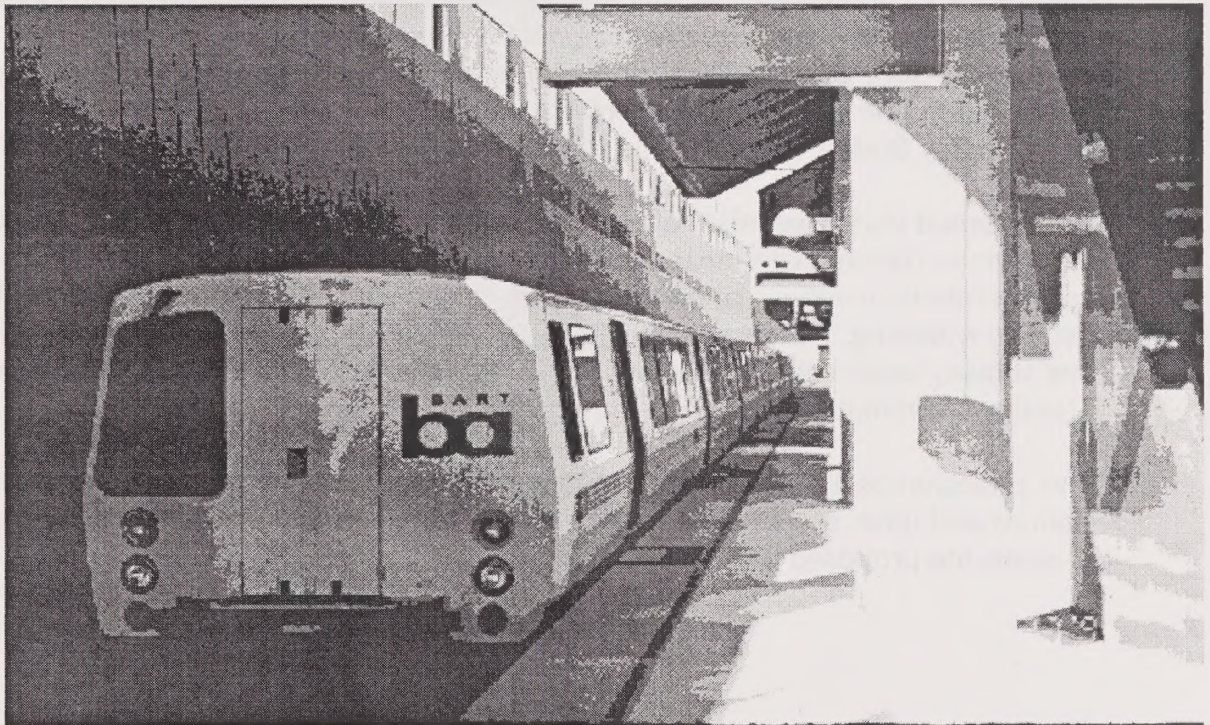
Line	From	To	Distance (miles)	Time (minutes)
OA, MH, BT	Transbay Tmnl.	Yerba Buena	3.3	6
OA, MH, BT	Yerba Buena	Oakland Harbor	3.7	6
OA, MH, BT	Oakland Harbor	40 th & San Pablo	1.1	4
OA	40 th & San Pablo	City Hall	1.8	7
OA	City Hall	East 14 th & Oak	0.6	3
OA	East 14 th & Oak	Foothill & Hegenberger	6.0	24
OA	Foothill & Hegenberger	Coliseum BART	1.8	7
OA	Coliseum BART	Airport	3.4	13
MH, BT	40 th & San Pablo	MacArthur BART	0.8	3
MH	MacArthur BART	Broadway & MacArthur	0.9	4
MH	Broadway & MacArthur	Mills College	5.5	22
MH	Mills College	Coliseum BART	2.6	10
BT	MacArthur BART	Telegraph & Ashby	2.2	9
BT	Telegraph & Ashby	Telegraph & Bancroft	0.8	3
BT	Telegraph & Bancroft	Berkeley BART	0.7	3
BT	Berkeley BART	University & M. L. King	0.9	4
BT	University & M. L. King	University & San Pablo	1.1	5
BT	University & San Pablo	Foot of University	0.9	4

ALTERNATIVE B – BART RELIEF LINE

BART's main peak capacity constraint in providing Transbay service is the section between the west end of the Oakland Wye and Daly City; in this segment, while there are crossovers available to turn trains back, there is no third track available. An additional route across the Bay, connecting into the existing BART system south of MacArthur Station, or into the main point of constraint at the Oakland Wye, then running independently to and over the Bridge to the Transbay Terminal, could provide considerable additional capacity.

Significant additional transbay BART capacity could be attained by taking one of the four present transbay BART lines out of the Transbay Tube and placing it on the Bay Bridge. Such a program would permit more frequent operation of that line, thus increasing its capacity. This would also create new peak-hour "slots" in the tube itself, thus making it possible to increase the total number of peak hour trains on other lines by four or five trains. An example of a BART car is shown on Figure 2-4.

**FIGURE 2-4
BART C CAR**



Clearly, either a connection from the Oakland Wye to the Bay Bridge, or from MacArthur Station to the Bay Bridge, and the re-routing of any present Transbay BART line, could be used conceptually for demand forecasting. Since the purpose of the evaluation at this point is to illustrate the potentialities of bridge rail alternatives, rather than to assess the strength of different BART bridge strategies, a reasonable case might be made for the selection of any of the BART possibilities. In this case, it will be assumed for initial working purposes that the greatest relative advantage to be gained for any BART line in moving it from the Transbay Tube to the Bay Bridge would probably be for the Richmond-Daly City line, operating over a MacArthur Station-Bay Bridge cutoff bypassing Downtown Oakland. As the Richmond-MacArthur segment is also served by the Richmond-Fremont service, direct service at all hours from all stations north of Ashby to Oakland would be retained despite the re-routing of Transbay trains over the Bay Bridge.

Route and Infrastructure

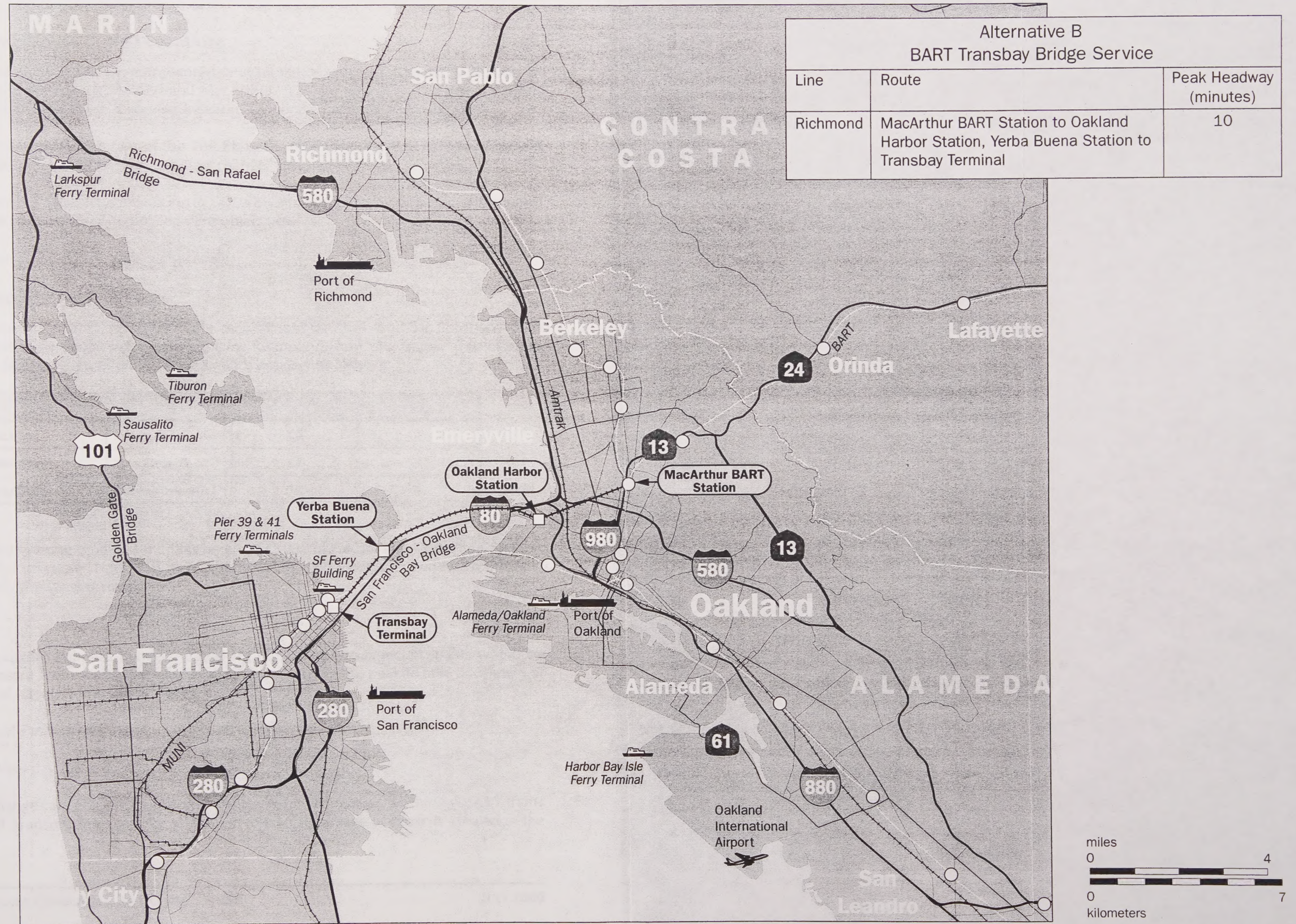
Conceptually, a new double-tracked BART connection would begin just south of MacArthur Station, with track connections arranged so that trains to the Bay Bridge could come from either track on the "southbound" platform, and trains from the Bay Bridge could reach either track on the "northbound" platform. This would require significant re-arrangement of the current track configuration at MacArthur. The structure with the Bridge tracks would begin to rise immediately, and curve west across the southbound lanes of Highway 24, entering the median of I-580. The structure would continue to a new elevated Oakland Harbor Station, on the south side of the bridge approach, near the toll plaza. The line would continue west onto the Bay Bridge, then over the Bridge to the Transbay Terminal upper level.

It is assumed that three miles of new reinforced concrete aerial structure would be built to connect the current mainline to the bridge. Some modifications to I-580 might be necessary, and potentially involve real estate acquisition if the BART structure's piers resulted in some freeway widening. There would be one fairly straightforward aerial station at Oakland Harbor, one subway station at Yerba Buena Island, and a more complex terminal arrangement at the Transbay Terminal.

The extension as a whole would involve approximately 8.9 miles of double track. Three stations and three sets of universal crossovers are assumed along the extension. Figure 2-5 presents the proposed BART alignment.

Figure 2-5

Bay Bridge Alternatives Study, Alternative B - BART Transbay Bridge Service



Stations and Park-and-Ride Locations

BART Richmond-San Francisco trains would serve all stations presently served by Richmond-Daly City trains between Richmond and MacArthur. On the new alignment, new stations would be constructed at the following locations (common to all rail alternatives):

- Oakland Harbor: East of the Toll Plaza to serve City of Oakland redevelopment objectives, and providing a “last chance” park-and-ride lot.
- Yerba Buena: A tunnel station in Yerba Buena Island to provide access and support for San Francisco redevelopment objectives.
- San Francisco: Transbay Terminal

Travel Times Between Stations

North of MacArthur station, travel times between stations for Richmond-San Francisco trains would be the same as they are at present for Richmond-Daly City trains. Travel times between Bridge line stations are estimated approximately as follows:

From	To	Distance (miles)	Time (minutes)
MacArthur	Oakland Harbor	1.9	3
Oakland Harbor	Yerba Buena	3.7	6
Yerba Buena	Transbay Terminal	3.3	6

The estimated running time of 3 minutes between Oakland Harbor and MacArthur Stations is based on the scheduled running time of 3 minutes between MacArthur and Ashby Stations, approximately the same distance.

Headway

Assumed headway (minutes between trains) for Richmond-San Francisco trains would be based on present Richmond-Daly City service, augmented in the peak to take advantage of the additional capacity created by the new line.

- AM Peak: 10 minutes
- Weekday Base: 15 minutes

No major changes are assumed for other transit systems. However, additional BART trains serving other Transbay lines may be scheduled to take advantage of capacity created in the

Transbay Tube. Alternatively, the enhanced capacity may be used to improve operational reliability.

Rolling Stock Assumptions

Taking one BART line out of the Transbay tube would provide additional capacity that could be added to other lines. Assuming that the existing Richmond-Daly City service could also be re-routed from the Transbay Tube onto the Bay Bridge, some additional peak service could also be added to boost capacity on this line. Additional capacity created in the Tube (four trains per hour) could then be used to increase service on other lines. For illustrative purposes in this paper, it is assumed that:

- a shortening of the peak headway on the Richmond Transbay line would be accomplished by taking advantage of the shortened running time to the Transbay terminal in comparison with Daly City and Colma, and running more frequent service with the number of trains presently assigned to the Richmond Transbay line; and
- four trainsets would be acquired to run more peak trains through the Transbay Tube and thereby increase capacity on other Transbay lines.

Assuming 10-car trains, and a 20% spare ratio, this would imply 48 cars.

Capacity

Assuming a shortening of the peak headway on the Richmond Transbay Line from 15 to 10 minutes, six 10-car trains per hour would be operated across the Bay Bridge in each direction. At 150% of seated load (68 seats), this would represent a delivered capacity of 6120 passengers per peak hour per direction. The line would be signalized for shorter headway, higher capacity operation if needed.

ALTERNATIVE C – BASIC BRIDGE RAILROAD PASSENGER SERVICE

Route, Infrastructure and Service Pattern

In this alternative, it is assumed that both an electrified commuter rail service and high speed trains would be operated up the Peninsula, through Downtown San Francisco's Transbay Terminal, and over the Bay Bridge. The line would be operated with FRA compliant trainsets illustrated in Figures 2-6 and 2-7. Figure 2-8 shows the alignment and station locations for a transbay commuter rail service.

FIGURE 2-6
FRA COMPLIANT REGIONAL RAIL

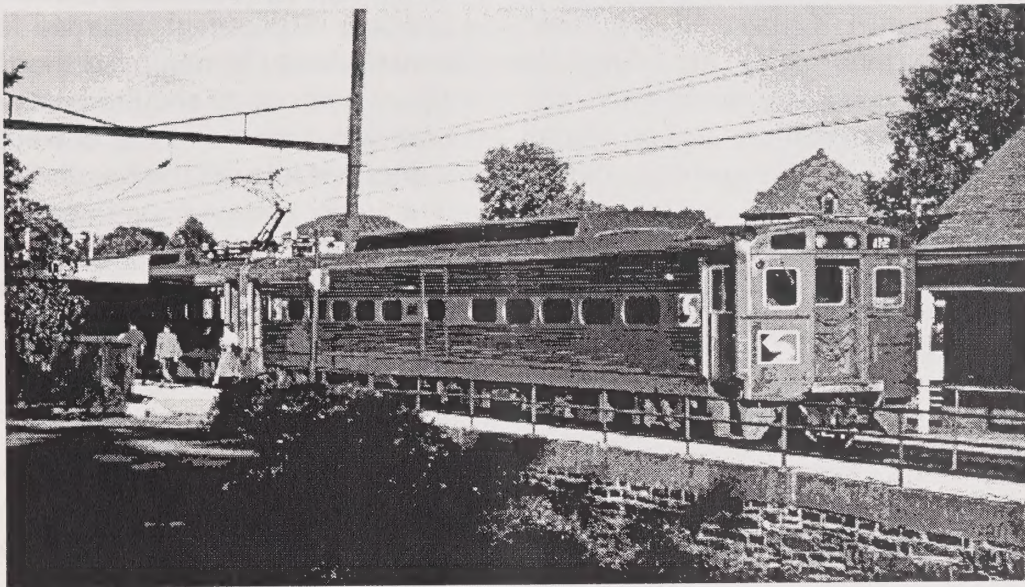
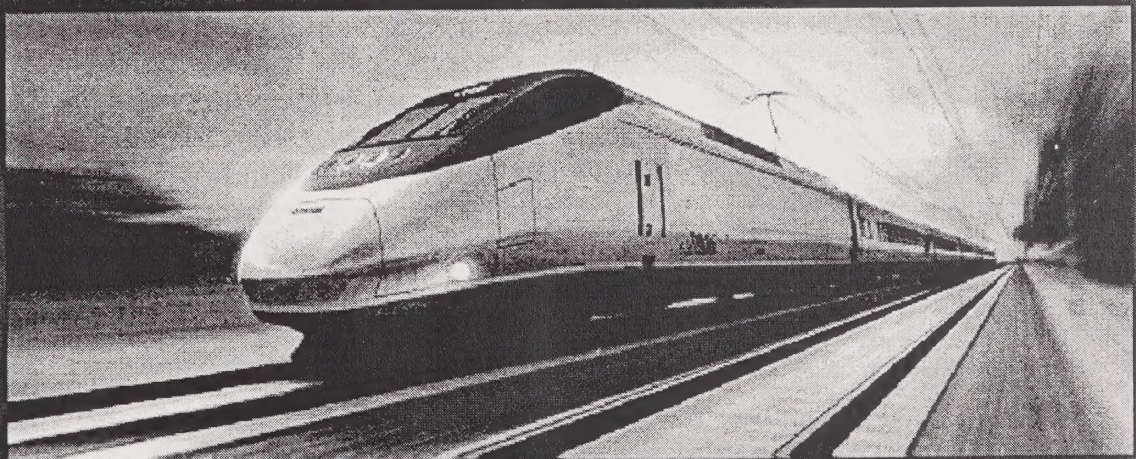


FIGURE 2-7
FRA COMPLIANT HIGH SPEED RAIL

High Speed Electric Train



Bridge trackage could also be used to provide a link between San Francisco and Oakland for California's potential high speed rail system. While trains would operate at conventional speeds on the Bridge, through service could in this way be provided from Southern California points to both East Bay and San Francisco stations. Equipment assumed for purposes of analysis was the Amtrak "Acela" high speed trainset, due to be deployed shortly in Northeast Corridor service. The Acela trainset is compliant with safety requirements of the Federal Railroad Administration, and represents the probable outer envelope of weight likely to be experienced with high speed equipment. This does not rule out the possibility that different, non-FRA compliant high speed equipment might, under certain conditions, be operationally co-mingled under FRA waiver with conventional FRA-compliant intercity passenger and commuter trains for a limited distance (essentially from Fourth and Townsend, via the Transbay Terminal and Bay Bridge to Oakland).

Key assumptions in this alternative are:

- From Fourth and Townsend Streets to the Transbay Terminal in Downtown San Francisco and then over the Bay Bridge to Oakland, high speed and commuter trains will both operate at conventional speeds, and share the same tracks.
- High speed trains will operate on a 30-minute headway in both directions.
- It is assumed that Caltrain is electrified using electric multiple unit trains (EMU), at least as far south as Tamien station in San Jose. Service to Gilroy may remain diesel operated initially.
- The skip-stop "A train/B-Train" concept used in MTCs "Blueprint" assumptions for Caltrain are assumed, including all assumed running times and station stops.

With this type of skip-stop operation, all stations are designated as an "A" station, a "B" station, or an "A + B" station. (All major stations are "A + B" stations.) Trains are designated either an "A" train or a "B" train. "A" trains stop only at "A" stations and "A + B" stations; "B" trains stop only at "B" stations and "A + B" stations. Trains therefore make fewer stops, and achieve faster running times, and all major stations have the benefit of being interconnected by fast trains on a short headway. The less busy stations still have good service with fast trains linking them to the major stations. The disadvantage is that travel from an "A" station to a "B" station requires a transfer from one train to another, and, in some cases, doubling back.

- All "A" and "B" trains are assumed to be extended from the present Caltrain Terminal at Fourth and Townsend Streets to the Transbay Terminal, then via the Bay Bridge to a West Oakland station near the Toll Plaza, referred to as Oakland Harbor Station for working paper purposes. This will be a major station, and the terminal for high speed trains coming from the Peninsula.
- "A" trains and "B" trains will each operate on a 30-minute base headway in both directions. The schedules will be evenly staggered so that the headway between the major stations (the "A + B" stations) will be 15 minutes.

- In general, peak passenger loads will be accommodated by lengthening trains from, perhaps, four cars in the base period to as many as ten cars in the peak. In the peak hour, an additional "A" train and an additional "B" train will originate in San Francisco for the Peninsula, but not run over the Bridge. In other words, commuter rail service over the Bridge will be the same as base level service (30 minutes on each, with a common 15-minute headway between common stations), but peak hour service between the Transbay Terminal and San Jose will be doubled (15 minute headway on each, with a 7½ minute headway between common stations).

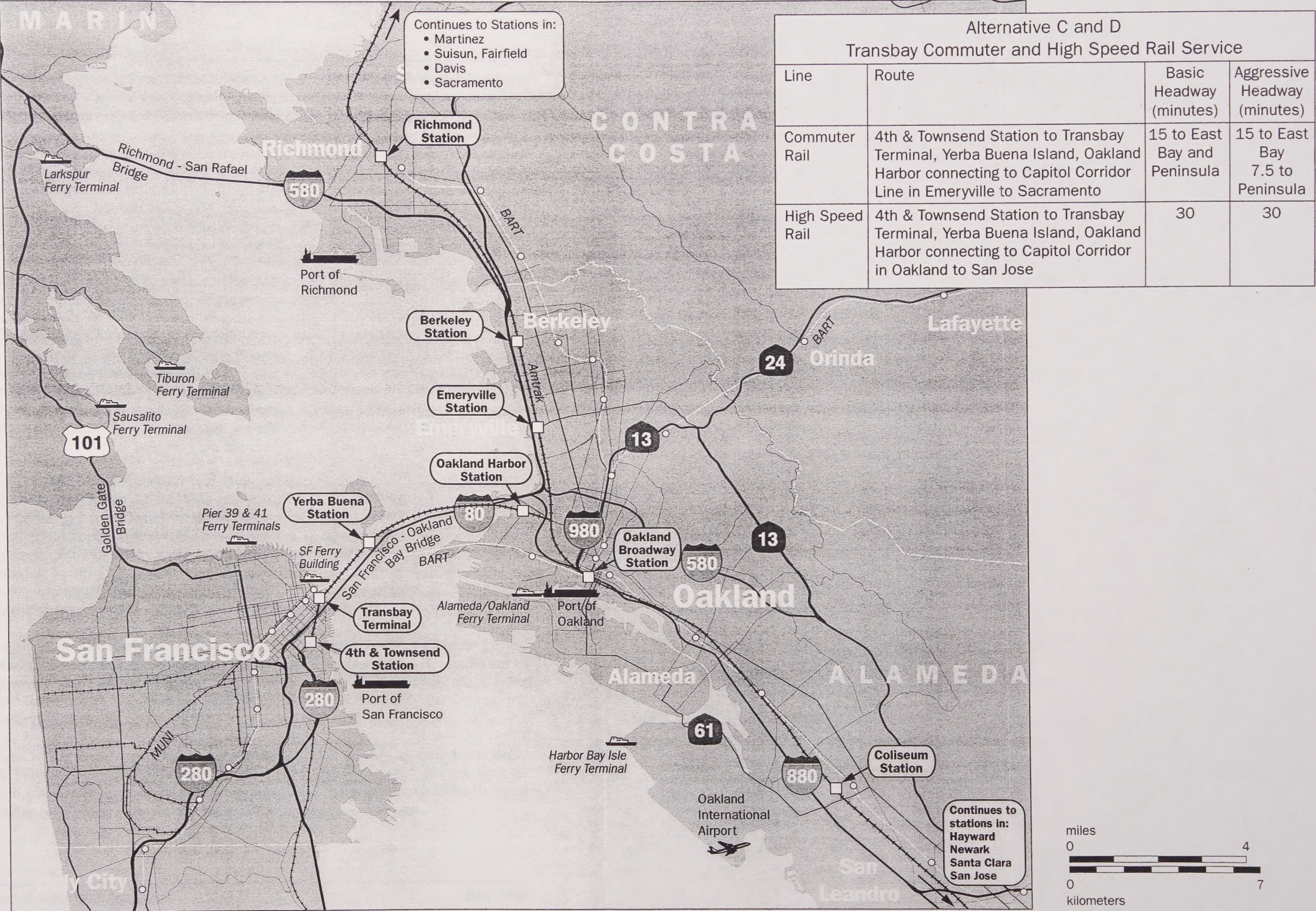
These service levels are assumed here for initial working purposes only. However, the signal system being considered in concept for the extension from Fourth and Townsend to Oakland, including the signalization of the six-track rail station in the Transbay Terminal, might permit reliable operation on a shorter headway, depending upon operating assumptions. When demand forecasts are completed, a balancing of patronage forecasts with capacity may suggest the desirability of providing more trains on a shorter aggregate headway.

- "A" and "B" commuter trains will stop at a Yerba Buena Island station.
- East of Oakland Harbor Station, the railroad line will divide as it passes over the Union Pacific mainline at the site of the former Interurban Electric grade separation. "A" trains will head north on a new track along the east side of the Union Pacific mainline, on a thirty-minute headway, stopping at Emeryville, and West Berkeley (foot of Gilman Street), terminating at Richmond BART station. "B" trains on a thirty-minute headway will turn south and run along a new track east and north of the Union Pacific mainline, stopping at 16th Street; they will then run along Third Street, stopping at Broadway and at Oak, where they will terminate. It is assumed that special treatment will be given to the design of Third Street trackage to accommodate pedestrians, traffic concerns and urban design features.
- From Richmond, it is assumed that some "A" trains will be extended as part of the Capitol Corridor Service to Sacramento on a two-hour base/ one-hour peak headway. For this alternative, it is assumed that the Capitol Corridor will not be electrified, but that the Bridge EMU trains will be incorporated into the consist of diesel-powered Sacramento-Oakland-San Jose trains. It is assumed that EMU cabs will be specified to be capable of providing either all-electric or diesel-electric control; for these through trains, an additional ten minutes will be built into the station dwell time at Richmond to accommodate the operational requirements for combining or separating trains. No additional stations will be assumed.

The routing option for basic FRA compliant rail service is shown in Figure 2-8.

Figure 2-8

Bay Bridge Alternatives Study, Alternatives C and D - Commuter and High Speed Rail Service Alignments



Track structure would follow typical UP freight mainline practices, with continuous welded rail on timber ties. The option to build new tracks with concrete ties also exists, and the choice will not seriously impact the cost of construction. Special fastenings may be required for the Bay Bridge, depending on how the structure is modified for rail.

Although much of the Union Pacific's mainline route through Oakland has been recently resignalled as part of the I-880 rebuild and Capitol Corridor Improvements, electrified operation would require much of this work be redone. Similarly, grade crossing warning circuitry would also have to be redone. However, while the circuitry would have to be redone, the technology for electrified operation would be relatively easy for the UP's signal maintenance crews to become familiar with.

The power system recommended for this service is 25 KV/60 Hz, readily available from local utilities. Increased clearances have been provided at overhead bridges to insure that all current rail freight cars will be able to pass safely underneath the catenary system. Unlike older electrified systems in the East, there would be no high voltage power transmission along the right-of-way. Instead, local utilities (PGandE) would be tapped along the routes where necessary.

Substations would be located along the line to provide utility connections, power management, and signal power. The passenger operating authority would have to contract with Union Pacific to develop forces for maintaining the overhead catenary and power distribution system.

It is assumed that Union Pacific's communications infrastructure would provide enough capacity for passenger operations in joint areas. For the Bay Bridge and any modifications required for joint areas, a system level allowance has been made. The Union Pacific has been assumed as the dispatcher of service, at least on the joint trackage. The train traffic on the Bay Bridge can be handled through an extension of Cal Train's dispatching territories.

The Basic passenger system would take advantage of existing stations where possible, with appropriate modifications for higher passenger volumes. New stations would be added at Oakland Harbor and Berkeley-Gilman Street. As noted above, Oakland harbor Station would be located near the junction of I-80 and I-880, just to the east of the Bay Bridge toll booths and will have a parking garage. All stations would have provisions for local bus access and layover, and kiss 'n ride spots. New tracks for terminating trains would be added at Oakland-Jack London Square and Richmond. New stations can be designed very simply because the proof of payment fare collection system would not require ticket clerks.

In the Basic service network, most, if not all of the additional trackage required could be added within existing railroad rights-of-way. The Union Pacific would expect the passenger operator to pay a fee for this usage; this has not been included in the capital cost estimates, but its inclusion in an annual operating budget could be anticipated.

Stations and Running Times

Where High Speed Rail (HSR) is shown in parenthesis under "Lines," it signifies that while high speed trains pass over this segment, they do not make the station stop in the "To Station" column. On the Bridge, assumed speed is approximately 50 mph; Transbay Terminal approach speeds to and from the Bridge are on the order of 15-20 mph due to grades and curvature.

FIGURE 2-9
BASIC RAIL SYSTEM RUNNING TIMES

Lines	From Station	To Station	Distance (miles)	Time (minutes)
A, B, HSR	4 th & Townsend	Transbay Tmnl.	1.6	5
A, B, (HSR)	Transbay Tmnl.	Yerba Buena	3.3	6
A, B, HSR	Yerba Buena	Oakland Harbor (HSR Terminal)	3.7	6
A	Oakland Harbor	Emeryville	1.5	3
A	Emeryville	West Berkeley	2.0	4
A	West Berkeley	Richmond BART (Terminal for most A Trains)	5.8	8
A	Richmond BART	Martinez	19.7	30 + 10 = 40
A	Martinez	Suisun-Fairfield	17.3	20
A	Suisun-Fairfield	Davis	26.7	24
A	Davis	Sacramento (Terminal for A/Capitol Corridor Trains)	13.4	20
B	Oakland Harbor	16 th Street	0.8	3
B	16 th Street	Broadway	2.6	6
B	Broadway	Oak	0.5	2

Park and Ride Locations

A major park and ride facility with access from toll plaza lanes is assumed at Oakland Harbor Station. Other park and ride facilities either are or will be located at Emeryville, Richmond, Martinez, Suisun-Fairfield and Davis.

Rolling Stock Assumptions

In the Basic option, it is assumed that Transbay rail service would be provided by electric multiple unit trains (EMUs), as an extension of electrified Caltrain service running through from the Peninsula via the new Transbay Terminal to the East Bay. Some of these EMUs could also be handled as coaches in diesel-powered Capitol Corridor trains between Richmond and Sacramento, in order to provide through train service from Sacramento to San Francisco and the Peninsula without having to electrify the Union Pacific mainline between Richmond and Sacramento.

Both Bridge railroad service options assume that electrified Caltrain commuter rail service is being provided from the Peninsula to the Transbay Terminal, and that most trains are extended through the Terminal to the East Bay via the Bay Bridge. Two half-hourly EMU commuter rail services are assumed to be provided across the Bridge, with schedules staggered to provide a 15-minute headway on the Bridge itself. Half the service ("A" trains) would turn north, and operate via Emeryville and Berkeley to Richmond. The other half ("B" trains) would turn south and run to Downtown Oakland. Each branch has a one-way running time from San Francisco of less than 30 minutes, so that round-trip running time would be one hour on each branch. With a 30-minute headway, two trains would be required for each branch, or a total of four trainsets plus spares.

It is assumed that during the peaks, all trains would be ten cars, or five married pairs, in length, so that 40 cars, or 20 married pairs would be required for the four trainsets. Assuming a 20% spare ratio, 8 spare cars, or 4 married pair would be required, yielding a total fleet of 48 cars, or 24 married pairs, spares included.

It was further assumed that through cars to Sacramento could be carried on some of the "A" trains to Richmond, operating as EMUs to Richmond, and as trailers in diesel-propelled Capitol Corridor trains from Richmond to Sacramento. Assuming a two-hour headway to Sacramento, and a two-hour running time from San Francisco to Sacramento, which includes ten minutes for switching at Richmond, and further assuming that one married pair would be run through between San Francisco and Sacramento in each Capitol train, two married pairs and one spare pair would be required.

As a final requirement, it was assumed in this option that California high speed trains entering San Francisco from the south, and reaching the Transbay Terminal over shared Caltrain trackage, would be extended over the Bay Bridge and terminate at Oakland Harbor Station. This extension could require at least one additional high speed trainset.

Capacity

Assuming a fifteen-minute combined commuter rail headway, plus two Acela high speed trains per hour, the capacity delivered across the Bridge would be 6600 passengers per peak

hour per direction. The line would be signalized for shorter headway, higher capacity operation if needed.

ALTERNATIVE D – AGGRESSIVE BRIDGE RAILROAD PASSENGER SERVICE

Route, Infrastructure and Service Pattern

This alternative has some basic similarities to Alternative C, in that it is assumed that both an electrified commuter rail service and high speed trains would be operated up the Peninsula, through Downtown San Francisco's Transbay Terminal, and over the Bay Bridge. The commuter rail service would be an extension of Caltrain through San Francisco to the East Bay, but in this "Aggressive" alternative, the northern "A" and southern "B" branches extend beyond the Central East Bay core cities. Alternate high speed trains would be extended at conventional but fast speeds to Sacramento over an electrified Capitol Corridor. The aggressive rail scenario is included on Figure 2-8.

Key features assumed in this alternative include:

- From Fourth and Townsend Streets to the Transbay Terminal in Downtown San Francisco and then over the Bay Bridge to Oakland, high speed and commuter trains will both operate at conventional speeds, and share the same tracks.
- High speed trains will operate on a 30-minute headway in both directions.
- It is assumed that Caltrain is electrified using electric multiple unit trains (EMU), at least as far south as Tamien station in San Jose. Service to Gilroy may remain diesel operated initially.
- The skip-stop "A train/B-Train" concept used in MTCs "Blueprint" assumptions for Caltrain, as described above under Alternative C, is assumed, including all assumed running times and station stops.
- All "A" and "B" trains are assumed to be extended from the present Caltrain Terminal at Fourth and Townsend Streets to the Transbay Terminal, then via the Bay Bridge to a West Oakland station near the Toll Plaza, referred to as Oakland Harbor Station for working paper purposes. It is assumed that this will be a redevelopment node for the City of Oakland. This will be a major station, and the terminal for alternate High Speed trains (those not extended to Sacramento, as explained below).

- “A” and “B” trains will each operate on a 30-minute base headway in both directions. The schedules will be evenly staggered so that the headway between the major stations (the “A + B” stations) will be 15 minutes.
- In general, peak passenger loads will be accommodated by lengthening trains from, perhaps, four cars in the base period to as many as ten cars in the peak. In the peak hour, an additional “A” train and an additional “B” train will originate in San Francisco for the Peninsula, but not run over the Bridge. In other words, commuter rail service over the Bridge will be the same as base level service (30 minutes on each, with a common 15-minute headway between common stations), but peak hour service between the Transbay Terminal and San Jose will be doubled (15 minute headway on each, with a 7½ minute headway between common stations).

These service levels are assumed here for initial working purposes only. However, the signal system being considered in concept for the extension from Fourth and Townsend to Oakland, including the signalization of the six-track rail station in the Transbay Terminal, might permit reliable operation on a shorter headway, depending upon operating assumptions. When demand forecasts are completed, a balancing of patronage forecasts with capacity may suggest the desirability of providing more trains on a shorter aggregate headway.

- “A” and “B” commuter trains will stop at a Yerba Buena Island station.
- East of Oakland Harbor Station, the railroad line will divide as it passes over the Union Pacific mainline at the site of the former Interurban Electric grade separation.
- “A” trains will head north on a new track along the east side of the Union Pacific mainline, on a thirty-minute headway to Martinez, with every “A” train (30-minute headway) in the peak period, and alternate “A” trains (60 minute headway) in the base period continuing to Suisun-Fairfield. Stations, some served by commuter trains, some by High Speed trains, and some by both (as noted in Figure 2-10) are assumed at Emeryville, West Berkeley (foot of Gilman Street), Richmond BART, Hilltop/Point Pinole, Hercules, Martinez, Benicia, Suisun-Fairfield, Davis and Sacramento.
- It is assumed that high speed trains will operate over the Bay Bridge on a 30-minute headway. Every other high speed train, providing an hourly headway, will be extended to Sacramento to provide the Capitol Corridor service; conventional diesel-powered Capitol Corridor trains will be withdrawn, and the equipment re-deployed elsewhere in the AMTRAK California system. Service now provided south of Emeryville and north of San Jose by the Capitol Corridor will be replaced by the “B” train commuter service, described below. Capitol Corridor passengers

traveling to and from stations between Oakland and San Jose will transfer at Oakland Harbor station. San Jose passengers to and from Capitol Corridor points north of Oakland would have direct hourly service to Sacramento using high speed trains via the Peninsula and the Bay Bridge.

- “B” trains will be used to provide a new commuter rail service between Oakland and San Jose. Running on a thirty-minute headway, “B” trains will turn south from the junction point located east of Oakland Harbor Station, and run along a new track east and north of the Union Pacific mainline, stopping at 16th Street; they will then run along Third Street, stopping at Broadway and at Oak. East and south of this point, it is assumed that the Union Pacific’s former Western Pacific line between Oakland and Fremont will be acquired for passenger use, and rebuilt and electrified. Stations are assumed at Coliseum BART, Hayward BART, Fremont-Centerville, Santa Clara- Great America, and San Jose-Diridon. In Oakland, it is assumed that special treatment will be given to the design of Third Street trackage to accommodate pedestrians, traffic concerns and urban design features.

Infrastructure Assumptions

In the Aggressive Bay Bridge railroad passenger service option, the rail network over the Bay Bridge to Richmond and Jack London Square would look much the same as it would with the basic option. Beyond those points, however, capacity would have to be added to local and through freight routes, each of which has unique issues associated with it. The Union Pacific has several concerns that would have to be addressed in order to make joint operation of freight and passenger service successful. These include:

- Current rail freight capacity and network performance must not be reduced.
- Union Pacific’s right to add future capacity for freight growth must be maintained.
- The addition of capacity for public purposes must not place an undue cost burden on Union Pacific for future freight capacity increases.

No capacity modeling was carried out in connection with this initial evaluation, but some broad observations can be used for illustrative purposes at this stage. It must be kept in mind, though, that firm conclusions about physical improvements which might be required for capacity purposes would require sophisticated analysis based on a rigorous methodology acceptable both to the UP and to the public sector.

Some of the passenger routing in the basic option enjoyed a more intensive passenger service in the past, and some of the pathways used by the UP’s predecessor, the Southern Pacific, for that service still exist. Also, with the decline of carload freight in favor of containers and unit train operations, local freight service is less demanding. Many local industries have been phased out in favor of housing and commercial development. In general, it appears that

capacity, with appropriate reinvestment, can be added for passenger service with relative ease in the immediate East Bay area.

However, outside of the immediate terminal area, capacity issues with respect to combined freight and passenger operations become more complex. When passenger projects are implemented, complex modeling efforts are required to determine what infrastructure investments are required. In a conceptual study, such analyses are beyond the scope of effort. Instead, improvements are provided that have been shown to provide congestion relief in prior cases.

In either the basic or aggressive case, the passenger operating authority would have to contract with the Union Pacific for access to its property. This contract would have to recognize the increased costs of maintenance, both fixed (associated with more assets) and variable (associated with usage). Typically, these contracts spell out the public investments required for a defined level (frequency, speed, schedule, etc.) of passenger service. Liability issues would have to be resolved as well.

West Oakland to Sacramento

On this segment, the aggressive option calls for commuter operation to Suisun-Fairfield and frequent intercity service beyond to Sacramento. From Emeryville to North Richmond, the four tracks provided in the basic service case would suffice. From Richmond to Suisun-Fairfield a third track would probably be required over most of the alignment because of the combined impact of commuter and intercity passenger services.

The only area where a third track would probably be prohibitively costly would be between Martinez and Benicia, where the UP crosses the Carquinez Strait on a double-track lift bridge. Since passenger and freight speeds will be similarly restricted over the moveable portion of this bridge, careful dispatching may be able to accommodate both freight and passenger volumes. Any delay resulting from congestion would probably not impair freight as much as passenger operations. Only a detailed operations simulation could forecast what level of passenger service could be reliably maintained. If additional capacity is eventually required in the future, a crossing without a moveable span might make sense, however the cost is likely to be quite high.

Another area of concern is the feasibility of adding a track in the environmentally sensitive Suisun Marsh segment between Benicia and Suisun-Fairfield. Grading for added roadbed capacity at this location, while difficult in current environmental thinking, may be preferable to the continued expansion of highway networks which are even more invasive, if the total environmental picture is considered. For the train densities proposed in this study, a third track across the marsh is included.

Beyond Suisun-Fairfield, the largest impediment to frequent intercity service would be the Yolo Causeway, between Davis and Sacramento. This section, now single tracked because

of the need for costly bridge construction, would have to have its double track restored; the capital cost estimates provided here include provisions for it.

To provide for Union Pacific's future growth, the new trackage added for passenger service has been costed on the basis of providing the same margin of room for expansion that now exists. That is, if there is now space for another track, there will also be space after the passenger expansion. In some cases, this results in costly grading, but the high value of this corridor for both freight and passenger traffic justifies a long term planning horizon. Some of the individual projects will have benefits for freight service as well, especially from North Richmond to Martinez where the route follows the edge of San Pablo Bay, with many curves and slow running speeds. One such project, included in this plan because of heavy local freight service requirements, is a new tunnel at Oleum. It would shorten passenger and freight running times. For the long term, additional projects of this type should be considered.

West Oakland to San Jose

There are three existing Union Pacific lines to between Oakland and San Jose. One, the "Mulford Line" running via Newark, is the Union Pacific's through freight route. Part of that route already carries Capitol Corridor trains as well as the Altamont Commuter Express (ACE) service. The route chosen for this service combines UP's former Western Pacific line leaving downtown Oakland, part of which must be restored to service, with the Newark route.

The former WP right-of-way is just sufficient for two tracks, but no longer is needed for through freight service. With only local freight operating, two main tracks should be sufficient far into the future. At Niles, a long connection is envisioned that would permit trains to turn onto the Centerville Line, already double tracked. The connection would shorten the existing run by more than a mile. This Centerville line intersects the UP's busy through freight line at Newark. The Centerville line once continued from Newark across San Francisco Bay on the Dumbarton Bridge to intersect the San Francisco Subdivision (now operated by Caltrain) at Redwood City. There is already considerable interest in reviving this route for passenger operations. One of the attractive parts of developing the route proposed here between Oakland and San Jose is that it dovetails with other passenger service needs. By turning the WP route into a passenger line, south of Jack London Square and up to the point where it reaches Newark, the passenger service would no longer interfere with through UP freight movements.

The largest problems with the proposed route to San Jose are on the segment from Newark to San Jose. This route, currently single track, crosses the environmentally sensitive wetlands that border the south end of San Francisco Bay. En route across these wetlands, the line crosses a moveable bridge. While not frequently opened, the bridge will restrict operating speeds as long as the moveable rails are in place. With through freight operations and a short passenger train headway, it is unrealistic to expect this segment of the line to be operated with single track. Even with double track, it would have a constraining effect similar to that of the

Martinez drawbridge on the Sacramento line. The solution costed for this study is a double tracked concrete bridge that rises just high enough to provide clearance on the water to eliminate the need for a moveable span. To maintain low gradients, this structure would total nearly four miles in length, but it would eliminate the need for additional permanent grading in the marsh. The length is dictated by keeping the gradient to a minimum of 0.4% to achieve a minimum 35 foot clearance over the water at the location of the former moveable span. An interlocking was assumed at the south end of the new alignment at Alviso to provide maximum operating flexibility.

In conversations with the Union Pacific, the railroad has stated a serious concern about the capacity of this segment to handle both the freight and passenger volumes anticipated. If capacity modeling should validate the railroad's statement, then other potential remedies might include upgrading the parallel Milpitas line as a freight relief route or leaving the present moveable bridge in place as a relief route to the new double-tracked bridge. Capacity analysis may also show that by moving service from the Oakland to Elmhurst line and the Hayward line to the former WP, that the improvement for through freight operation in those areas may help mitigate delay south of Newark. In any case, the Newark to San Jose segment would be among the most expensive in the electrified network. This analysis assumes that the electrification of the Caltrain Peninsula service would provide the electrification for the Bay Bridge trains from Santa Clara to San Jose.

Stations and Running Times

Where high speed rail (HSR) is shown in parenthesis under "Lines," it signifies that while high speed trains pass over this segment, they do not make the station stop shown in the "To Station" column. High speed trains providing the Capitol Corridor service are assumed to make all stops presently being made by Capitol Corridor trains between Oakland and Sacramento; new commuter rail stations are added for service by commuter trains only. On the Bay Bridge, maximum assumed train speed is approximately 50 mph; Transbay Terminal approach speeds to and from the Bridge are on the order of 15-20 mph due to grades and curvature.

FIGURE 2-10
“AGGRESSIVE” RAIL SYSTEM RUNNING TIMES

Lines	From Station	To Station	Distance (miles)	Time (minutes)
A, B, HSR	4 th & Townsend	Transbay Tmnl.	1.6	5
A, B, (HSR)	Transbay Tmnl.	Yerba Buena	3.3	6
A, B, HSR	Yerba Buena	Oakland Harbor	3.7	6
A, HSR	Oakland Harbor	Emeryville	1.5	3
A, HSR	Emeryville	West Berkeley	2.0	4
A, HSR	West Berkeley	Richmond BART	5.8	8
A, (HSR)	Richmond BART	Hilltop/Point Pinole	4.1	6
A, (HSR)	Hilltop/Point Pinole	Hercules	4.7	7
A, HSR	Hercules	Martinez	10.9	17
A, (HSR)	Martinez	Benicia-I680	5.9	10
A, HSR	Benicia-I680	Suisun-Fairfield (Terminal for commuter trains)	11.4	10
HSR	Suisun-Fairfield	Davis	26.7	22
HSR	Davis	Sacramento (Terminal for High Speed trains)	13.4	18
B	Oakland Harbor	16 th Street	08	3
B	16 th Street	Broadway	2.6	6
B	Broadway	Coliseum BART	4.7	7
B	Coliseum BART	Hayward BART	8.8	13
B	Hayward BART	Newark-Centerville	12.5	16
B	Newark-Centerville	Santa Clara-Great America	13.9	16
B	Santa Clara-Great America	San Jose-Diridon	5.8	12

Rolling Stock Assumptions

In the aggressive Bay Bridge railroad alternative, both the EMU commuter rail and the high speed rail elements are present, but they are extended beyond the more immediate catchment area of the Central East Bay, as described in Working Paper 3A.1. To the north, "A" commuter trains coming from the Peninsula are routed through the Terminal, across the Bay Bridge, and north along the Capitol Corridor (Union Pacific mainline) to Martinez, with alternate trains extended to Benicia and Suisun-Fairfield. To the south, "B" commuter trains are extended through Oakland, and along the Union Pacific's ex-Western Pacific line to Niles Jct. (Fremont), then over the Centerville and Newark lines to Santa Clara and San Jose.

Capitol Corridor trains would be discontinued in their present form, and replaced by conventional speed but fast extensions of the California high speed trains, running on an hourly headway. Thus, Sacramento-to-San Jose service would operate via the Bay Bridge, the Transbay Terminal, SFO and the Peninsula. As it is assumed that high speed trains are running on a 30-minute headway overall, alternate high speed trains would terminate at Oakland Harbor Station.

It is estimated that this service pattern would require 13 EMU sets, or 78 married pairs inclusive of spares, and 5 Acela high speed trainsets.

CHAPTER 3. STRUCTURAL FEASIBILITY ANALYSIS

The structural impact of rail transit on the Bay Bridge is dependent on the type of rail system selected. Figure 3-1 shows the system weight and clearance envelope required for each alternative rail system. The current Caltrain system has also been included for comparison.

FIGURE 3-1
RAIL SYSTEM WEIGHT AND CLEARANCE DATA

Rail System	Loaded Rail Car Weight in lbs. per linear foot of track	Rough Rail Envelope Size (height by width)	
		Single Track	Double Track
BART	1,170	14' by 16'	14' by 32'
Light Rail	1,390	18' by 16'	18' by 29'
SEPTA	1,720	26' by 17'	26' by 34'
Amtrak – Acela (high speed)	1,800	26' by 17'	26' by 34'
Caltrain – Current System*	1,900	26' by 17'	26' by 34'

**Included as a basis of comparison.*

The train cars in the first systems are individually powered. The Amtrak Acela and Caltrain have locomotives powering the train sets that are considerably heavier. The higher locomotive loads may control the final design of some bridge components but, for this study, the main length of the train sets, the passenger cars, are the basis of comparison.

It is important to note that all of the technologies considered for Transbay rail service are electronically powered. BART's electric power is via a third rail alongside the rails for the vehicle wheels. The other three systems access electrical power from overhead wires referred to as catenaries. Diesel fueled systems were not considered appropriate for this crossing due to the likelihood of an indoor stop at the current or reconfigured Transbay Terminal in San Francisco. While diesel buses do use the terminal, their operation allows for easy engine stopping and starting during waiting times. The diesel locomotives used in train sets do not offer this capability.

Any analysis of the impacts of rail on the Bay Bridge requires three separate analyses:

- Analysis of the west (suspension) spans
- Analysis of the Yerba Buena Tunnel system
- Analysis of the east (cantilever spans)

For the purposes of this analysis, the impacts of rail were studied on the post-retrofit West spans and on the proposed rebuilt East spans. Some additional analysis was done to determine the impact of rail on a retrofitted East span.

WEST SPAN STRUCTURAL COMPONENT DEAD AND LIVE LOAD PERFORMANCE – SEISMIC RETROFIT AND NO RAIL

Structural design capacity calculations completed in 1965/67 provided the suspension bridge dead and live load demands and associated capacities for a representative number of components within the superstructure. With these values, “demand to capacity” ratios (D/Cs) can be developed for each member type. The ratios are valuable for ease in reporting and reviewing the performance of a structure. D/C ratios greater than 1.0 indicate that the structural element in question does not have the code required strength to carry the load. D/C ratios less than 1.0 indicate sufficient code required structural capacity.

Figure 3-2 contains the D/C ratios for the main elements of the superstructure. Note that these are the service load demands. The “1959 Reconstruction” numbers come directly from the 1965/67 investigation calculations. The “1999 Current” numbers reported are determined by factoring the dead and live load demands from the 1965/67 demands by the increase or decrease in loads.

FIGURE 3-2
RETROFITTED WEST SPAN DEMAND TO CAPACITY RATIOS
ASSUMES NO RAIL

	Seismic Retrofit No Rail	1999 Current	1959
Main Cable	0.94	0.90	0.91
Suspenders	0.74	0.71	0.71
Towers	1.17	–	–
Top Chord	0.94	0.70	0.70
Bottom Chord	1.00	0.76	0.76
Diagonals	1.12	0.94	0.47

For service loads only. Seismic loads will alter these results

These values are a worst case scenario for members in each category. These numbers in no way signify that each diagonal for the “Seismic Retrofit” scenario will require strengthening. Rather, the worst case will be to increase the strength of only a few members by 12% and the remainder by less or not at all. In very general terms, a 10% increase in total load would

likely be tolerated for service load conditions. However, more in-depth analysis is required to determine the structure's tolerance to added loads.

LOCATION OF RAIL SERVICE ON THE WEST SPANS

Another key factor in analyzing the structural impact of rail on the suspension spans is the location of the rails relative to the traffic lanes and structural elements. After a preliminary analysis of a number of options, three proved to be viable:

- Adding Lanes Below Deck
- Adding Lanes Alongside the Lower Deck
- Adding Lanes Alongside the Upper Deck

It should be noted that lanes were added in all cases to ensure that capacity not be removed from the bridge. While auto lanes could be removed in favor of rail operation, the growing demands for Transbay travel projected by MTC suggest that removing auto capacity would not be desirable.

1. Below Deck

This option adds two lanes to the bridge below the current lower deck. Either traffic lanes or bi-directional train traffic could utilize this deck, created under the existing stiffening truss by hanging a level below, as shown in Figures 3-3 and 3-4.

**FIGURE 3-3
BELOW DECK OPTION**

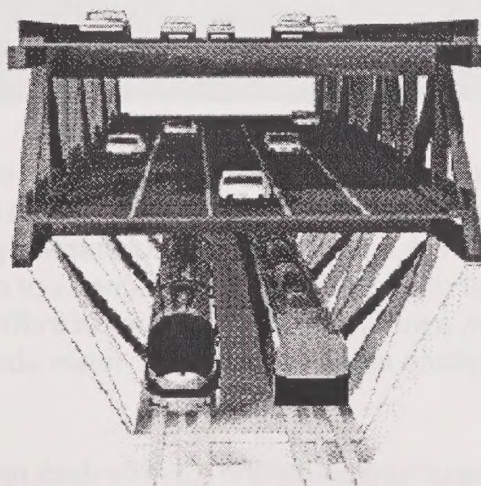


Figure 3-4 provides a simulation showing how the bridge might look looking east from San Francisco.

FIGURE 3-4
SIMULATION OF BELOW DECK OPTION



In this option, it would also be possible to run rail service on the lower deck of the bridge and to use the lanes below the bridge for auto traffic. Such a design would reduce the headroom required for the new deck, but would not substantially alter the structural impacts of the alternative at this level of analysis. If two directions of rail service are placed on the bridge deck in any alternative, a minimum of three lanes of traffic would be displaced. The remedial action would be to replace at least three traffic lanes above, below or beside the West span stiffening truss.

The option of adding structure below the existing deck requires at least some reduction in the clearances for shipping. The United States Coast Guard must approve any reductions in vertical clearance. Preliminary indication is that they would be very concerned about reductions in clearance due to the placement of a radio beam for navigation and because

vessels continue to get larger over time. This issue would need considerable attention in further studies.

Lower Side by Side

This option adds bi-directional rail service by symmetrically widening the stiffening truss on either side of the lower deck of the suspension span to accommodate rail or vehicles on the outside of the existing suspension cables as shown in Figures 3-5 and 3-6. Again, it should be noted that additional study is required to determine the advantages of using the new lanes for rail or auto service. Should auto traffic be placed outside of the current truss, a total of four lanes would be replaced, to allow for balanced loads.

FIGURE 3-5
LOWER SIDE BY SIDE OPERATION

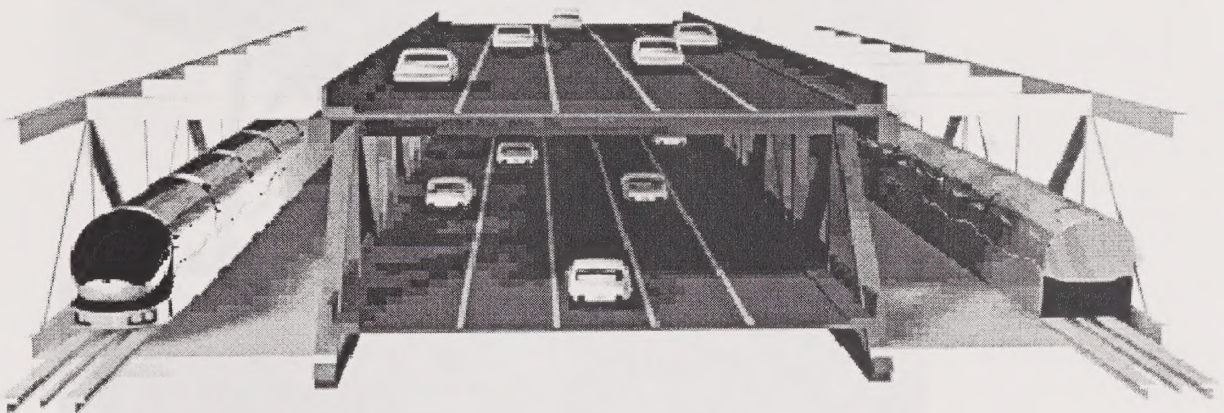


FIGURE 3-6
SIMULATION OF LOWER SIDE BY SIDE OPTION



While either of the side-by-side rail options have some advantages, a key problem is that they are unable to drop down to the basement level of Transbay Terminal, which is the preferred location for a rail station, connecting Peninsula service to downtown and the bridge.

Upper Side by Side

This option is similar to the Lower Side By Side option, except that the new travel ways would be at the upper deck levels. This option is shown in Figures 3-7 and 3-8.

FIGURE 3-7
UPPER SIDE BY SIDE OPTION

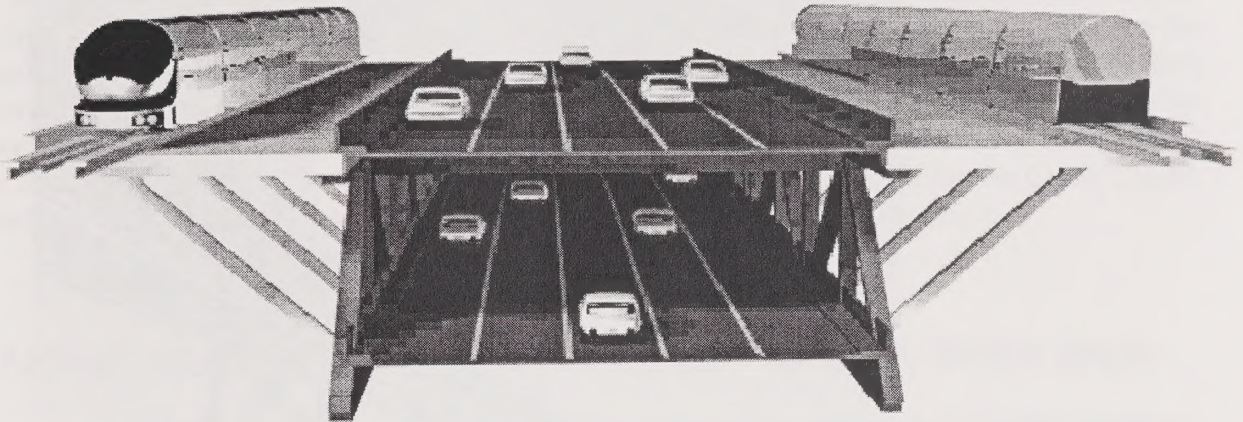


FIGURE 3-8
SIMULATION OF UPPER SIDE BY SIDE OPTION



NON-STRUCTURAL CONSIDERATIONS

As part of the feasibility analyses, the study team and peer advisor panel were able to draw a number of conclusions about each alternative that go beyond strictly structural issues. These non-structural considerations may ultimately prove as important as structural feasibility or cost. They include construction safety and impacts, aesthetics and opportunity for connections within Transbay Terminal. A summary of findings is presented in Figure 3-9. The below deck option appears preferable because of the flexibility it offers at Transbay Terminal. It is the only option that can access the basement, unless rail were placed on the bridge deck, moving auto lanes outside the truss on a side-by-side option. The below deck option will also minimize impacts to ramps on Yerba Buena Island and in San Francisco. However, additional study is required to determine whether the reduction in maritime clearances that would be required under this alternative are acceptable to the Coast Guard. Therefore, all three configuration options are carried forward in this analysis.

FIGURE 3-9
NON-STRUCTURAL CONSIDERATIONS – RAIL ON WEST SPAN

Issues	Below Deck	Upper Side by Side	Lower Side by Side
Construction Safety	Pro: Work is below traffic.	Pro: Work is outside of traffic	Pro: Work is outside of traffic
Traffic Impacts during construction	Con: Individual lane closures are likely.	Con: Individual lanes closures are likely.	Con: Individual lanes closures are likely.
Catastrophic derailment – Train attempts to leave the rail corridor and collides with a portion of the bridge	Pro: New framing would be damaged. The main truss would remain stable	Likely elements damaged would be the suspender cables and main cables. Pro: Loss of suspender cables does not produce an unstable condition. Con: Damage to main cables would be difficult to repair.	Con: Loss of truss chords, diagonals, and verticals would lead to possible collapse of the truss.
Aesthetics	Con: Adds depth to the stiffening truss	Con: Adds width to the stiffening truss and minimal depth	Con: Adds width to the stiffening truss and minimal depth
Access to all levels of the Transbay Terminal	Pro: Access to the Transbay Terminal is not restricted. Entering Rincon Hill through the anchorage is possible	Con: Can not drop to basement level. Dropping sufficiently below grade for a Rincon Hill tunnel is not possible without hanging the decks off the existing truss well east of the approach to SF. Aesthetically undesirable.	Con: Can not drop to basement level. Dropping sufficiently below grade for a Rincon Hill tunnel is not possible without hanging the decks off the existing truss well east of the approach to SF. Aesthetically undesirable.
Yerba Buena Island crossing	New tunnel bore below the existing.	New tunnel bores on each side of the existing.	New tunnel bores on each side of the existing.

FIGURE 3-9 (CONT.)

NON-STRUCTURAL CONSIDERATIONS – RAIL ON WEST SPAN

Issues	Below Deck	Upper Side by Side	Lower Side by Side
Impacts on shipping clearance	Con: Reduction in shipping clearance by approximately 24 feet	Pro: No reduction in shipping clearance.	Pro: No Reduction in shipping clearance.
Final configuration traffic flow	Pro: No impact on the bridge or YBI.	Con: Will require reworking some YBI and San Francisco off ramps	Con: Will require reworking some YBI and San Francisco off ramps
Caltrans Maintenance Operations	Con: Providing moving maintenance clearance below the existing lower deck will further encroach on shipping clearances.	Pro: Shipping Channel encroachment is considerably less than "Below Deck". Side access maintenance gantries can remain.	Maintenance vehicles can use upper deck of widening. Side access maintenance gantries can remain provided the bridge rail is suitably outboard of the existing truss.
Steel Truss long-term Service Life	Pro: Member demands will generally be a function of the vertical load and are not as likely to cycle from tension to compression.	Con: Member demands will be a function of vertical and torsional load cycles and cycling is possible. Additional joint strengthening may be required.	Con: Member demands will be a function of vertical and torsional load cycles and cycling is possible. Additional joint strengthening may be required.
Conflicts with adjacent structures.	Pro: No conflicts provided rail enters a Rincon Hill Tunnel.	Con: Air rights have been given for a building 10 feet north of the SF anchorage. The building will be as tall as the bridge.	Con: Air rights have been given for a building 10 feet north of the SF anchorage. The building will be as tall as the bridge.

WEST SPAN STRUCTURAL COMPONENT DEAD AND LIVE LOAD PERFORMANCE – WITH RAIL, STRENGTHENING AND SEISMIC RETROFIT

While the location of rail on the bridge would ultimately be an important consideration in a more detailed structural analysis, the three location options were not independently analyzed at this feasibility stage.

Load Impacts of Rail on the West Spans

Adding 34 feet of deck either as a widening or by adding a level below the existing lower deck is the minimum width required to permit bi-directional train operation. The added structural weight would require strengthening of the stiffening truss, which in turn would add further structural weight. Finally, there would be additional seismic retrofit required due to the weight and stiffness changes, which would again increase the weight. Figure 3-10 summarizes the weight impacts of adding bi-directional rail service on the West spans of the Bay Bridge. The impact of each of the four rail technologies (BART, Light Rail, Commuter Rail

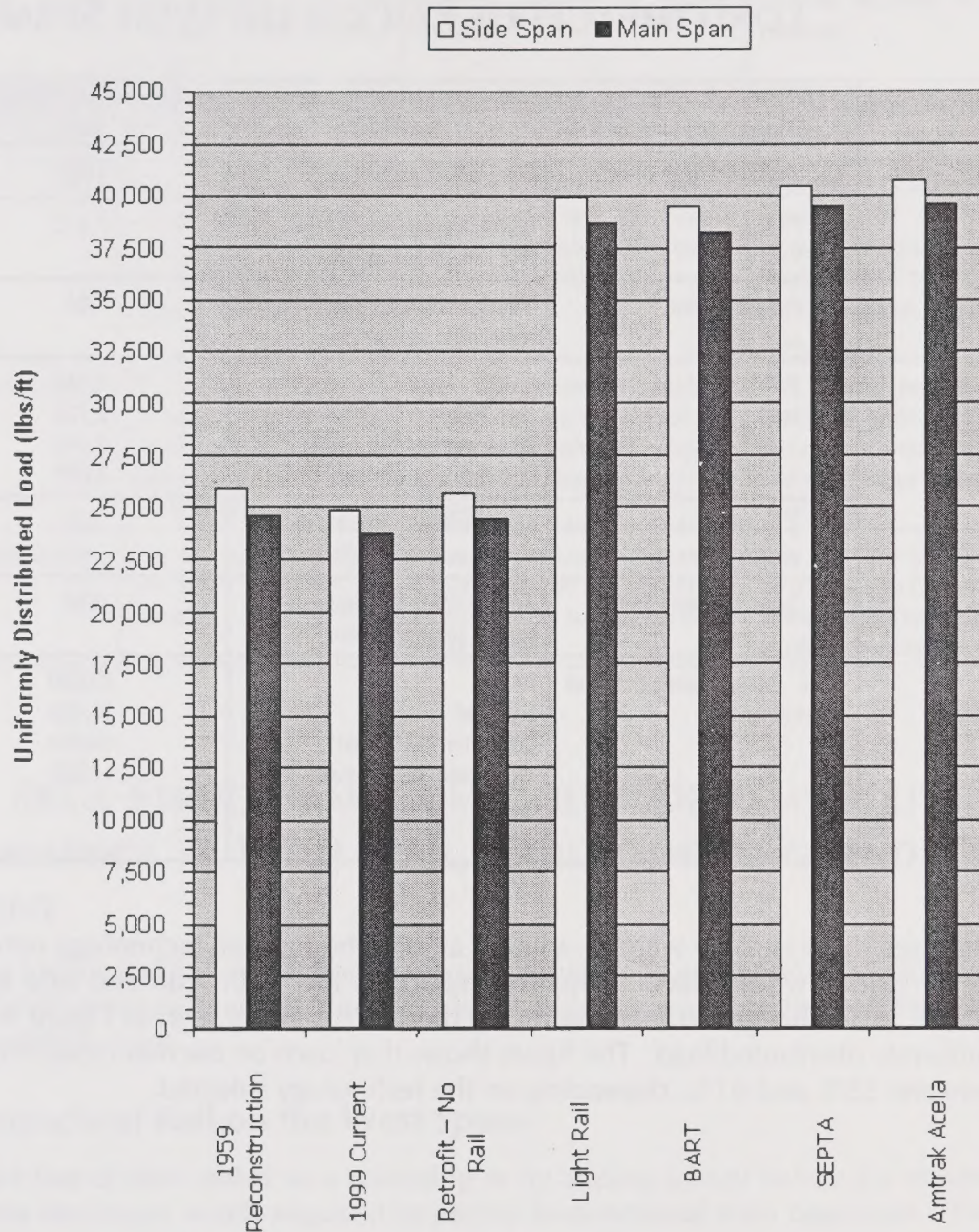
and High Speed Rail) would differ because the live load of each rail system is different, as previously discussed.

FIGURE 3-10
LOAD IMPACTS OF RAIL ON THE WEST SPANS

Incremental Increase	Description	Weight in pounds per linear foot
1. Additional Deck Area	Steel Superstructure	5,920
	Normal Weight Concrete Deck, 34 feet wide, 8 inches thick	3,400
2. Rail Equipment	4 Rails, fasteners, -plinths, power and control systems, etc.	300
3. Rail Live Load - Two tracks	BART	2,340
	Light Rail	2,780
	Commuter Rail (Septa)	3,440
	High Speed Rail (Amtrak)	3,600
4. Strengthening to accommodate rail	Approximately equal to the current seismic retrofit	800
5. Second Seismic Retrofit	Approximately equal to the current seismic retrofit	800
Total Added Load Per Rail System	BART	13,560
	Light Rail	14,000
	Commuter Rail (Septa)	14,660
	High Speed Rail (Amtrak)	14,820

Although there is some weight variation among the four rail technology options, any one of these options would have a negative impact on the main span and side spans of the Bay Bridge. The changes in load values on these elements is seen in Figure 3-11, assuming a uniformly distributed load. The figure shows that loads on the main span would increase by between 55% and 61%, depending on the technology selected.

FIGURE 3-11
LOAD IMPACT OF RAIL SYSTEMS ON BRIDGE SPANS



Using the structural capacities discussed previously and the loading capacity required for the four rail systems, it is possible to develop demand/capacity ratios for key structural members with each of the four rail technology options.

FIGURE 3-12
DEMAND/CAPACITY RATIOS FOR WEST SPAN MEMBERS
WITH RAIL AND ADDED DECK AREA

	2000			
	Lt. Rail	BART	Commuter Rail	HSR
Towers	2.01	1.89	2.20	2.25
Top Chord	1.19	1.11	1.31	1.34
Bottom Chord	1.25	1.17	1.37	1.40
Diagonals	0.85	0.79	0.94	0.96
Main Cables	1.40	1.38	1.42	1.42
Suspenders	1.14	1.12	1.16	1.16

For Service Loads only. Seismic Loads will alter these results.

As expected with such large load increases, the structure would require strengthening. Note that the values shown in Figure 3-12 do not suggest that rail is infeasible, they do suggest that significant effort will be required to avoid impacting the main cables.

Insufficient capacity in the main cable is one of the greatest strength obstacles to overcome in a suspension bridge. Adding rope to strengthen the existing main cable is usually complicated by protective cable wraps, suspender saddle, tower saddle and anchorage constraints. When all other solutions are exhausted, adding a second set of cables is an option. The following section briefly describes alternatives that could reduce structural weight and therefore lower demand.

Options to Reduce Structural Demand

Immediate structural weight reduction could be achieved by replacing the existing concrete decks with lighter materials. Three deck options were assessed for weight savings: replacing the normal weight concrete on the lower deck's south side with lightweight concrete, orthotropic steel deck and composite fiber decks. Lightweight concrete and orthotropic steel are common decking materials. Composite fiber systems have only recently been developed and are in limited experimental application on far less essential structures. While the

composite fiber may become an accepted decking material in time, it is not currently used by Caltrans and was not considered in detail in this study. The weights per square feet of area for 8" thick decks are given in the following table.

FIGURE 3-13
WEIGHT REDUCTION POTENTIAL
OF LIGHT WEIGHT ROADWAY DECKS

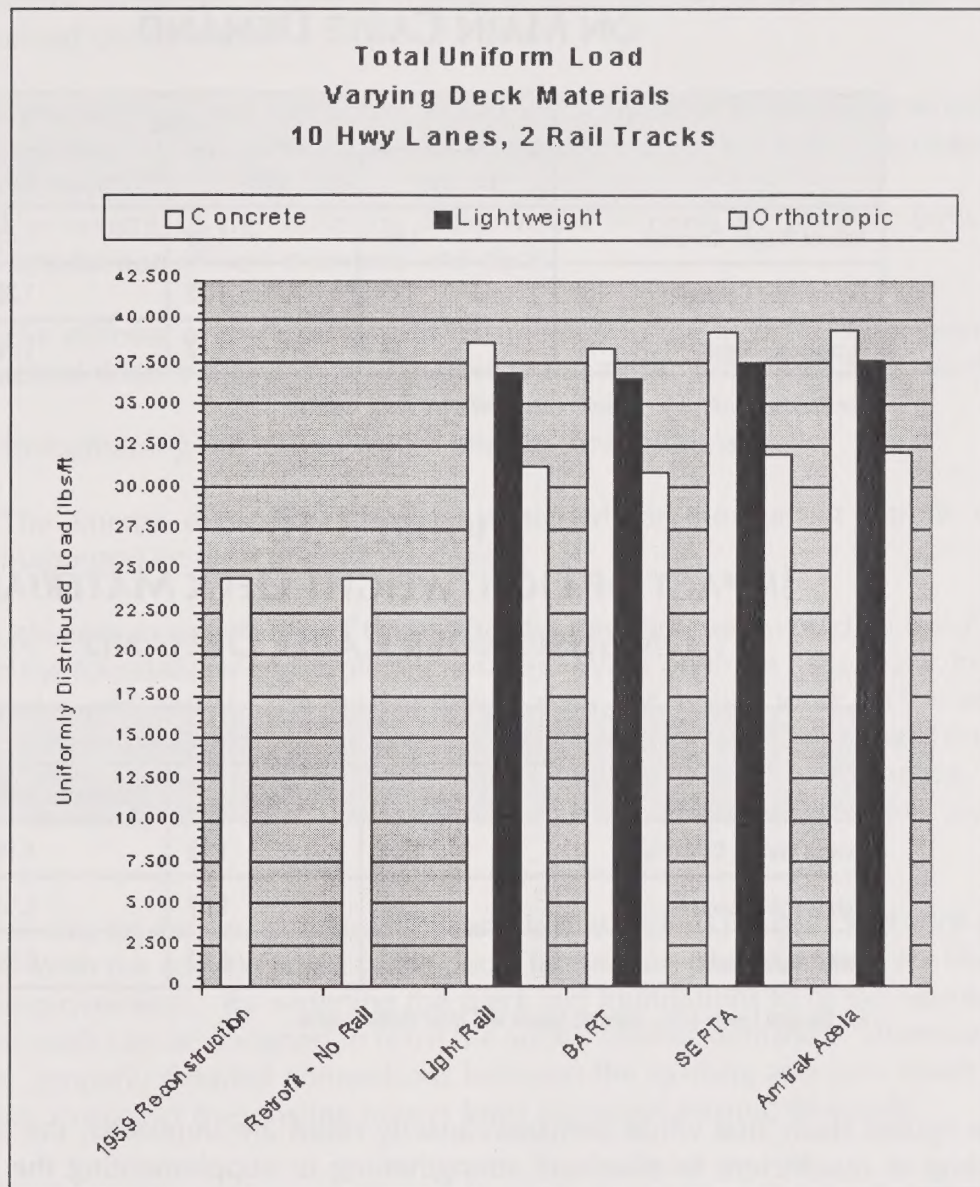
System Type	Weight in Pounds per Square Foot	Weight Savings in Pounds per Linear Foot of Bridge
Current: 8" Lightweight concrete throughout except normal weight concrete on the south side of the lower deck	90 (Average)	–
8" Lightweight Concrete Throughout	83	770
Orthotropic Steel Throughout	45	5,220

To provide a protective wearing surface for the concrete slabs on the West spans, Caltrans has installed a 3/4-inch epoxy overlay. For the proposed deck systems, this report assumes an equivalent surfacing. Fully developed deck designs could increase or decrease this thickness. The resulting change in added load would not change the conclusions of this feasibility study.

Combining the weight savings of the deck options presented above with the loads from the various rail options changes the load impacts of rail on the main cable as seen in Figure 3-14. The range of load increase on the main cable and suspender cables, assuming an orthotropic steel deck, can be reduced to an increase of between 25% and 31%, depending on the technology selected.

It should be noted that no significant study has been completed to determine the life-cycle implications of using an alternate decking material on the Bay Bridge Roadway.

FIGURE 3-14
WEIGHT IMPACTS OF RAIL OPTIONS
ASSUMING LIGHT WEIGHT DECKING MATERIAL



Revised demand/capacity ratios with various decking options are shown below:

FIGURE 3-15
IMPACT OF LIGHTWEIGHT DECK MATERIAL
ON MAIN CABLE DEMAND

	2000			
	Lt. Rail	BART	Commuter Rail	HSR
Normal Weight Concrete	1.40	1.38	1.42	1.42
Lightweight Concrete	1.33	1.32	1.35	1.36
Orthotropic Steel	1.14	1.12	1.16	1.17

For Service Loads only. Seismic Loads will alter these results.

FIGURE 3-16
IMPACT OF LIGHTWEIGHT DECK MATERIAL
ON SUSPENDER CABLE DEMAND

	2000			
	Lt. Rail	BART	Commuter Rail	HSR
Normal Weight Concrete	1.14	1.12	1.16	1.16
Lightweight Concrete	1.09	1.07	1.10	1.11
Orthotropic Steel	0.93	0.91	0.95	0.95

For Service Loads only. Seismic Loads will alter these results.

The figures show that while demand/capacity ratios are improved, the amount of weight savings is insufficient to eliminate strengthening or supplementing the main suspension cables.

West Span Seismic Considerations

Added weight is not the only impact to the Bay Bridge Structure. The addition of rail service would have significant seismic impacts, requiring further retrofit. In very basic terms, the properties that control a bridge's behavior under a defined seismic event are:

- **Mass** – how much the structure weighs and where the weights are in the structure.
- **Stiffness** – how much the structure moves when subjected to a given force.

More complex aspects of a structure's seismic performance include the lateral framing system's material properties, as well as internal or external devices that dissipate energy and reduce sustained cyclic motion.

The added structure for two rail tracks would certainly alter these characteristics of the seismically retrofitted West spans. Adding rail would result in the following changes:

- The weight of the stiffening truss would increase by roughly 50% with the introduction of new members and deck.
- The stiffness of the truss would change due to the new structural members, the added deck width, and any changes to the existing roadway deck materials.
- Strengthening the towers would change their stiffness.
- The energy dissipating dampers designed for the current retrofit would be inappropriate for a revised West span.

One of the greatest consequences of retrofitting the new structure would be the difficulty in working on the foundations and cable anchorages. Work on these deep-water foundations is very complex and costly. The current retrofit does not require work on the tower piers beyond increasing the capacity of the connection between the steel towers and the concrete piers. With the proposed new rail decks and the altered seismic performance, increased foundation demands and subsequent foundation and anchorage retrofits are a likely possibility.

Some benefit may be derived from the rail scenario that widens the deck and adds tower legs and cables. With the added weight of the deck, foundation improvements are likely, as are tower leg improvements. By widening the piers and foundations to fit the new tower legs, much of the work can be designed to resist the added seismic demands. Likewise, up at the tower level, properly detailed connections between the existing and new tower legs offer opportunities to protect the existing towers from increased seismic demands.

THE IMPACT OF RAIL OPERATIONS ON THE PROPOSED EAST SPANS

The Proposed East Spans

Following the Loma Prieta earthquake, Caltrans and its consultants undertook a number of studies related to the options for seismic strengthening of the Bay Bridge. While a retrofit plan was developed for the west suspension spans, it was determined that the East spans would be replaced. Replacing the East spans could be achieved at about the same cost as seismic retrofits, while providing a new structure with a long life-cycle. This study assumes the proposed replacement spans as the condition on which rail is imposed.

The width of bridge is sufficient to allow for an additional lane with rail although the design does not provide for the needed structural capacity. Geometrically, there is sufficient space to have five lanes and no shoulders, provided a lane width of 11'10" is acceptable to the reviewing agencies. As reported earlier, the West spans currently operate with 11'7" lane widths. The potential East span 11'10" lanes could possibly win approval from Caltrans. Also, depending on which train set is used, the rail width could be reduced to allow for both greater lane width and/or additional narrow shoulder. Structural capacity must be added to accept this configuration.

Load Impacts of Rail on the Proposed East Spans

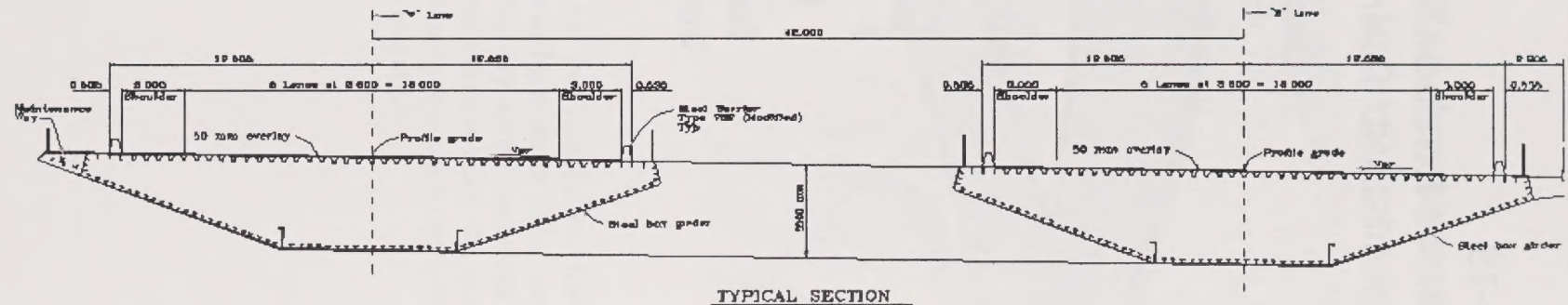
Structurally, there are both service load and seismic concerns with five lanes and rail. The current East span design criteria call for live loads representing four lanes and one track at 1,400 pounds per linear foot.

Percent increase in live load from the current East span criteria of 1,400 pounds per linear foot of rail and four lanes, compared to the heaviest bridge rail alternative and five lanes of traffic, is 27%. With the lightest rail option, it is an 8% increase. Again, using this simplified comparison is appropriate for the level of study reflected in this report. More accurate conclusions require detailed analysis to fully document the increased demands of each structural component.

Greater opportunities to maintain the existing ramps and simplify rail and vehicle operations would exist if rail were moved to the exteriors of the East span decks. The main benefit is on the eastern side of Yerba Buena Island. Exterior tracks can be readily split off the main decks permitting many possible alignments through new tunnels in Yerba Buena Island. With alignment options available, placing track outside of the West spans remains an option and would permit keeping five lanes of traffic together in each direction on these spans.

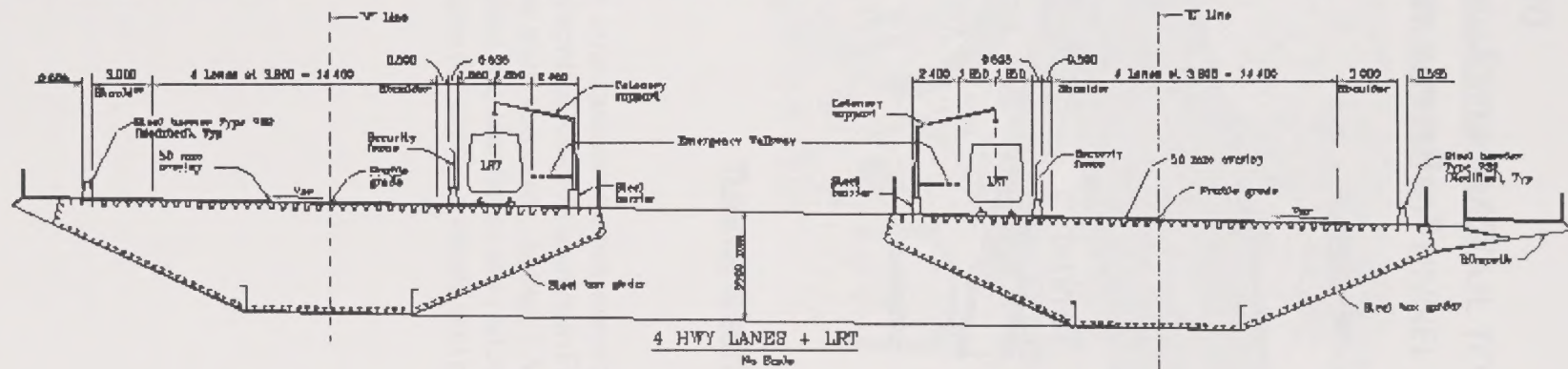
Figure 3-19 shows alignments for rail on the exterior dropping down to a bore below the existing roadway tunnel. Alignments that parallel the existing tunnel are shown in Figure 3-20.

FIGURE 3-17
CURRENT PROPOSED EAST SPAN TYPICAL SECTION – 5 LANE DESIGN



Courtesy of Caltrans and T.Y. Lin International/Moffat & Nichols, a Joint Venture

FIGURE 3-18
CURRENT PROPOSED EAST SPAN TYPICAL SECTION – 4 LANE DESIGN WITH LIGHT RAIL



Courtesy of Caltrans and T.Y. Lin International/Moffat & Nichols, a Joint Venture

FIGURE 3-19
RAIL ALIGNMENT – EAST SPAN’S EXTERIOR RAIL
TO BELOW THE YERBA BUENA ISLAND TUNNEL

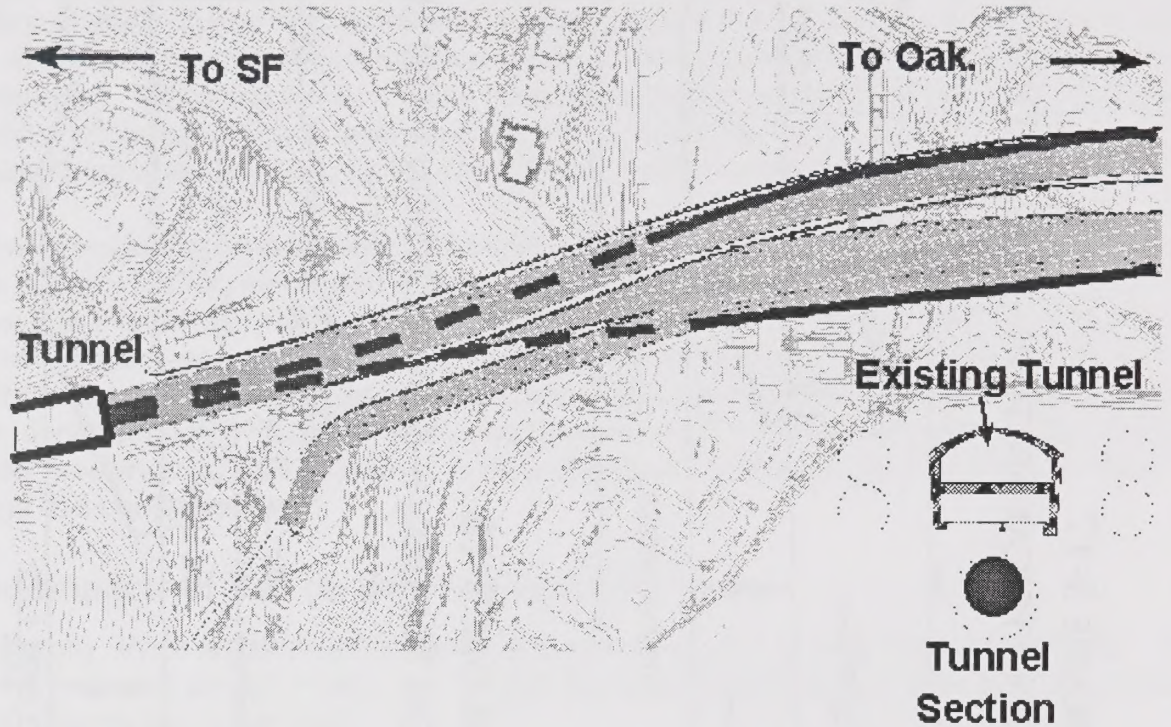
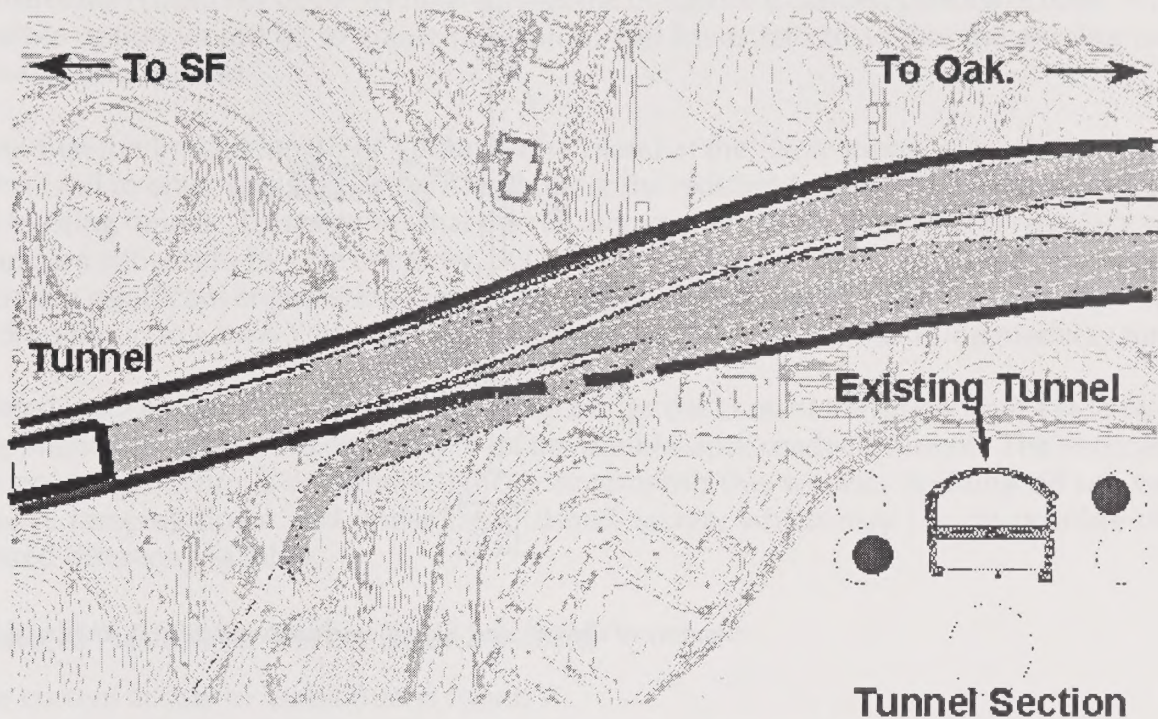
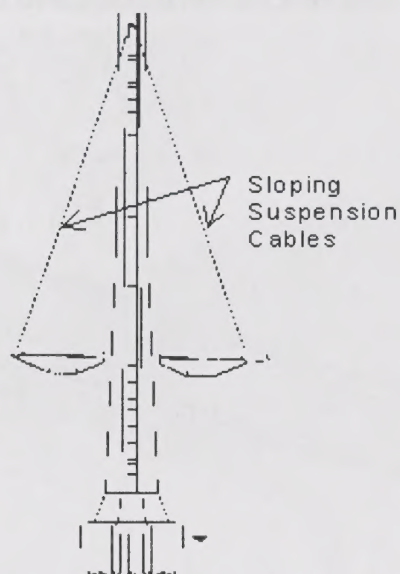


FIGURE 3-20
RAIL ALIGNMENT – EAST SPAN’S EXTERIOR RAIL TO
EACH SIDE OF THE YERBA BUENA ISLAND TUNNEL



Currently, for the East spans, the suspension cable arrangement slopes inward from the connection at the exterior of the deck up to the central control tower as shown in Figure 3-21. Rail and catenary wire clearances required for all the train scenarios, except BART, would result in interference with the suspender cables unless the shoulders are reduced for the vehicles. Ideally, the deck needs to be widened to move the cables outward and provide the necessary clearance.

FIGURE 3-21
EAST SPANS SECTION



Courtesy of Caltrans and T.Y. Lin International/Moffat & Nichols, a Joint Venture

From a traffic perspective, the deck should also be widened to accommodate the full five lanes. The current design width is 59'4" which is greater than the 58'0" on the West Side. For proper 12'0" lanes and one-foot shoulders, the East span decks need to be widened by 2'8".

YERBA BUENA TUNNEL

Revising the usage of the upper and lower decks to a mixture of cars and trucks in 1959 required reconfiguring the support system of the upper deck. Structurally, allowing trucks on the upper deck increased the load on that deck. There was also a headroom problem which limited clearances for trucks on the outside lanes of the upper level in 1959. As a result, the columns between the vehicles and trains in the lower level, which supported the upper level, were removed. The upper deck was reconstructed with a prestressed floorbeam system that spanned from tunnel wall to tunnel wall at a lower elevation to provide headroom for trucks.

Live load code requirements for the deck in the tunnel have remained unchanged since the 1959 reconstruction. The lower level is a reinforced concrete slab constructed on a grade. Placing rail on this structure should not require alterations to the lower level support system. Rail on the upper deck, however, would compromise the floorbeams as the load changes

from 2,400 plf today to over 3,000 plf with three lanes and one track or 3,680 plf with two lanes and two tracks. These values are for BART, the lightest system.

Reconstructing the tunnel to support the additional loads is not a reasonable option since construction could not occur without closing the bridge for extended periods of time. A more feasible option would be to create new rail tunnel bores for rail so that the existing tunnel remains undisturbed.

Note that the limited length of Yerba Buena Island at the likely tunnel elevation would not permit rail to enter one side of the island under the existing tunnel and depart up alongside the existing tunnel. This requires that the rail alignments at both the east and west face of the island are either side-by-side or below, but not a combination. While either option is feasible, there are significant engineering concerns about an option that requires rail on the East spans to drop down to a new Yerba Buena rail tunnel located below the existing roadway tunnel.

Immediately east of Yerba Buena Island, the bridge decks must transition from a side-by-side alignment to a stacked alignment to meet the double-deck roadway tunnel. The vertical and horizontal geometry is extremely tight to accomplish this weave. Splitting off rail would require ramping down and under the planned weave, which may not be possible in the limited distance available.

Vehicle Access to Yerba Buena Island

The current access to Yerba Buena Island is:

- Eastbound traffic exits to the north side of the bridge on the west side of Yerba Buena Island and to the south side on the eastern side of the island.
- Entrance to the eastbound direction is from the south on the East Side of the island.
- Westbound traffic exits on the southeast.
- Entrances to the westbound lanes are on the northeast and northwest.

Westbound rail on the south side of the westbound structure would require new vehicle exit ramps to Yerba Buena Island. With eastbound rail on the north side of the eastbound structure, the vehicle exit ramp on the east side of the island would be eliminated. These impacted ramps could be relocated with sufficient funds and the needed environmental clearances.

CHAPTER 4. STRUCTURAL COSTS

Developing a cost estimate for adding rail to the Bay Bridge requires a separate analysis of the costs of structural changes to the bridge and the costs of rail infrastructure, including rails, rolling stock and signal systems.

Estimating the costs of the structural impacts of rail is further complicated by the fact that, on the West spans, rail would be added to a bridge that is already over 60 years old, and requires continuous traffic operations. Modifying the proposed East spans for rail operations is more straightforward because the design is not complete and construction will occur outside of current bridge operations.

Among the complexities of placing rail on the West spans which affect this cost estimate are:

- lead based paints
- custom-fit connections
- connections to, and modification of, fully loaded members
- working with traffic
- irregular foundations in deep water
- criticality of stage construction on a 60-year-old structure

These added costs are further inflamed by confined work areas on the San Francisco approaches due to occupied facilities and work over shipping channels that must remain clear. Because of these complexities, it is especially difficult to identify “peer projects” that might provide linear foot costs for a feasibility level cost estimate.

As a means of comparing these costs with other projects in the Bay Area, the proposed East spans are currently estimated to cost \$1,000 per square foot for the suspension spans and \$650 per square foot for the viaduct spans. Retrofit of the Golden Gate Bridge was in excess of \$1,000 per square foot in 1991, and there was no planned foundation work on the suspended spans. In year 2000 dollars, the square foot cost could easily be \$2,000. Internationally, the completion of the Oresund Link Cable-Stayed Bridge between Sweden and Denmark is \$1,000 per square foot. The bridge has relatively shallow inexpensive foundations and seismic risk did not control the design. Considering complexities of working with an existing structure on the West spans, values of \$2,000 per square foot are appropriate. Lower unit costs are, of course, assumed for other structures. These are relatively high-end estimates, which could be reduced through careful engineering at later study phases.

Figure 4-1 summarizes the structural costs of the rail alternatives, excluding all rail infrastructure costs. The West span costs dominate the calculation, requiring over \$1 billion in investment on that span alone. Total costs vary between \$3 billion and \$3.3 billion, exclusive of rail infrastructure.

FIGURE 4-1
STRUCTURAL COST SUMMARY
(EXCLUDES INFRASTRUCTURE)

	Options	
	Below	Side-By-Side
San Francisco Approaches	193	436
West Spans	1,334	1,447
Yerba Buena Island	317	198
East Spans*	546	546
Oakland Mole	60	40
Subtotal	2,450	2,667
25% Contingency	612	667
Total	\$3,062	\$3,333

Costs are in Millions

**East span costs are based on revisions to the design prior to awarding the construction contract.*

Figure 4-2 details this costs estimate.

FIGURE 4-2
STRUCTURAL COST ESTIMATE

Description	Below							Side By Side						
	Cost in Millions	Unit	Price	Quantity	Length	Width	Number	Cost in Millions	Unit	Price	Quantity	Length	Width	Number
San Francisco Approaches														
Tunnels	\$25	LF	\$25,000	1,000	1,000	1	1	\$0	LF	\$25,000	-	1,000	1	0
Viaducts	\$0	SF	\$500	-	0	20	1	\$40	SF	\$500	80,000	2,000	20	2
Continuous Spans	\$60	SF	\$1,000	60,000	1,000	30	2	\$60	SF	\$1,000	60,000	1,000	30	2
Ramp Revisions	\$108	SF	\$500	216,000	1,500	36	4	\$36	SF	\$500	72,000	1,000	36	2
Land or Air Rights Acquisition	\$0	LS	\$0	1	1	1	1	\$300	LS	\$300,000,000	1	1	1	1
	\$193							\$436						
West Spans														
Continuous Spans	\$40	SF	\$1,000	40,000	1,000	40	1	\$60	SF	\$1,000	60,000	1,000	30	2
Suspended Spans Superstructure	\$744	SF	\$2,000	372,000	9,300	40	1	\$837	SF	\$1,500	558,000	9,300	30	2
Center Anchorage	\$100	EA	\$100,000,000	1	1	1	1	\$100	EA	\$100,000,000	1	1	1	1
SF and YBI Anchorage	\$150	EA	\$75,000,000	2	1	1	2	\$150	EA	\$75,000,000	2	1	1	2
Towers Foundations	\$300	EA	\$75,000,000	4	1	1	4	\$300	EA	\$75,000,000	4	1	1	4
	\$1,334							\$1,447						
Yerba Buena Island														
YBI Approaches	\$20	SF	\$1,000	20,000	500	40	1	\$30	SF	\$1,000	30,000	500	30	2
Ramp Modifications	\$72	SF	\$500	144,000	1,000	36	4	\$72	SF	\$500	144,000	1,000	36	4
Tunnels	\$45	LF	\$30,000	1,500	1,500	1	1	\$60	LF	\$20,000	3,000	1,500	1	2
Approach Viaducts from East spans	\$180	SF	\$500	360,000	1,800	100	2	\$36	SF	\$500	72,000	1,800	20	2
	\$317							\$198						
East Spans *														
Deck Widening (Rail to the Exterior)	\$106	SF	\$1,200	88,000	11,000	4	2	\$106	SF	\$1,200	88,000	11,000	4	2
Deck Strengthening	\$440	SF	\$200	2,200,000	11,000	100	2	\$440	SF	\$200	2,200,000	11,000	100	2
	\$546							\$546						
Oakland Mole														
Fly-Overs	\$45	SF	\$750	60,000	1,500	20	2	\$30	SF	\$750	40,000	2,000	20	1
At grade rail	\$15	SF	\$250	60,000	1,500	20	2	\$10	SF	\$250	40,000	1,000	20	2
	\$60							\$40						
Subtotal	\$2,450							\$2,667						
25% Contingency	\$612							\$667						
Total	\$3,062							\$3,333						

* East spans costs are based on revisions to the design prior to awarding the construction contract.

CHAPTER 5. RAIL INFRASTRUCTURE AND ROLLING STOCK COSTS

The previous chapter estimated the costs of structural changes to the Bay Bridge required by any of the rail options. The total cost for implementing rail service would go well beyond bridge structural costs to include the cost of rail infrastructure, signalization and rolling stock. This chapter provides a feasibility level cost estimate for each of the four rail service options, outlined in detail in Chapter 1.

Costs presented in this chapter are independent of the costs associated with the structural preparation of the bridge itself for installation of a rail mode. It is assumed that the Bridge reconstruction costs would produce a "rail ready" structure, capable of accepting the installation of any of the potential rail options. It should be noted that this chapter considers only the capital costs of implementing each of the rail options, including infrastructure and rolling stock. Operational costs would be substantial, and are not included in any of these estimates.

The following table presents the overall estimated capital cost range, in 1999 dollars, of the various alternatives. The remainder of this chapter discusses the assumptions behind these numbers.

FIGURE 5-1
RAIL INFRASTRUCTURE AND ROLLING STOCK COSTS

Alternative	Infrastructure*	Rolling Stock	Total
A. Transbay Light Rail Service	\$1.4 billion	\$210 - \$315 million	\$1.6 - \$1.8 billion
B. BART Transbay Bridge Service	\$1.8 billion	\$144 million	\$1.94 billion
C. Basic Bridge Railroad Service	\$774 million	\$144 million	\$918 million
D. Aggressive Bridge Railroad Service	\$4.3 billion	\$461 million	\$4.77 billion

* Infrastructure includes all estimated project contingency (40%) and engineering (30%), including that applied to rolling stock.

This would bring the total cost of rail implementation, including bridge structural enhancements, rail infrastructure and rolling stock to a combined total of between \$4 billion and \$9 billion.

TRANSBAY LIGHT RAIL CAPITAL COSTS

1. Definition of Line Segments for Costing

The Transbay light rail transit (LRT) system is defined as a "main stem" using the Bay Bridge from the Transbay Terminal to 40th and San Pablo, plus three branches: "OA" from 40th and San Pablo via City Hall and Coliseum BART to the Oakland Airport, "MH" from 40th and San Pablo via MacArthur BART to Coliseum BART, and "BT" from MacArthur BART via Telegraph Avenue and Berkeley to the foot of University Avenue. Note that "BT" shares the "MH" line between 40th/San Pablo and MacArthur BART, while "MH" also traverses the "OA" segment from Foothill/Hegenberger to Coliseum BART. For facilities costing purposes, it is the discrete physical line segments that are of interest. Route miles are needed to estimate the LRV fleet size.

Segment	Description	Links	"OA"	"MH"	"BT"
TB-SP	<u>Main Stem:</u> Transbay Terminal-40th/San Pablo	8.1	8.1	8.1	8.1
SP-CH	<u>Oakland-Foothill-Airport:</u> 40 th /San Pablo-City Hall	1.8	1.8		
CH-FH	City Hall-Foothill/Hegenberger (73 rd)	6.6	6.6		
FH-CB	Foothill/Hegenberger-Coliseum BART	2.8	2.8	2.8	
CB-OK	Coliseum BART-Oakland Airport	3.4	3.4		
SP-MB	<u>MacArthur Boulevard:</u> 40 th /San Pablo-MacArthur BART	0.8		0.8	0.8
MB-FH	MacArthur BART-Foothill/Hegenberger (73 rd)	6.2		6.2	
MB-BB	<u>Telegraph-Berkeley-University:</u> MacArthur BART-Berkeley BART	3.7			3.7
BB-FU	Berkeley BART-Foot of University	2.9			2.9
	Totals	36.3	22.7	17.9	15.5

Inspecting the table, it may be seen that the three service routes total 56.1 route miles over the physical network of 36.3 line miles.

2. General Comment on Basis for Cost Estimate

A Transbay/Eastbay LRT system has been generally defined, as described herein; however, no actual engineering work has been done. Thus, the basis for this conceptual cost estimate must be acknowledged as "zero percent" of design. Cost estimates are based on recent experiences in Portland, Oregon, and San Jose and could easily differ in this environment.

3. Construction

Construction includes the fixed facilities along the LRT right-of-way. These are principally: utilities and street work, structures, roadbed and track, and stations.

- a. Utility Relocation. As compared to other projects, the innovative “shallow trench” track design is expected to reduce interferences with underground utilities and, as a result, relocation costs. This is reflected in the relatively low unit cost for this item.
- b. Civil/Roadway. It is not anticipated that building-to-building or even curb-to-curb reconstruction of streets will be done as part of this project, but that street work will be limited to modifications necessary to re-contour and otherwise blend adjacent lanes with the LRT lanes after the track has been installed.
- c. Aerial Structures. Two sub-categories are used. A relatively small allowance is provided for LRT-specific work on the Bay Bridge (i.e., apart from the major work of renovation and partial replacement contemplated in the Caltrans program). Elsewhere, new double-tracked aerial structures are assumed at the following locations:
 - ▶ MB-FH: 3 structures, at 200 linear feet (LF) each, where MacArthur crosses I-580
 - ▶ CB-OK: 2 structures, 500 LF crossing I-680, and 1,000 LF at the Airport
 - ▶ BB-FU: 1 structure, 1,000 LF crossing the Union Pacific Railroad and I-80
- d. Roadbed & Track. The entire system is assumed to be double-tracked. Two types of track construction are assumed: open track using ties and ballast or fixed to the Bay Bridge structure, and embedded track, with rails in street paving. Open track is assumed to be used on the entire TB-SP section, as well as along the median of Hegenberger (FH-CB and CB-OK). All other segments are costed for embedded track.

A rough track schematic was prepared to estimate requirements for special trackwork, with all track switches (turnouts) and crossings costed at a single amount per unit. Thus, a universal crossover is costed as 4 turnouts + 1 crossing diamond, and so on. Station and lay-up trackage is provided at the Transbay Terminal. Pocket tracks are assumed at 40th/San Pablo, Coliseum BART, and Berkeley BART. Interlocked crossovers and/or junctions are located at Transbay, Yerba Buena, Oakland Harbor, 40th/San Pablo, MacArthur BART, Foothill/Hegenberger, Coliseum BART, Oakland Airport, Berkeley BART and the foot of University. Hand-operated emergency crossovers are provided about every two miles on the branches.

- e. Stations. It is assumed that on the branches, LRT stations would be placed at intervals averaging about 0.5 miles. Passenger stations are assumed to be simple concrete platforms with bus-type shelters, lights, and a basic passenger information display (kiosk, signing). Transit centers to provide for LRT/bus transfers are assumed at 40th/San Pablo, City Hall, Coliseum BART, MacArthur BART, and Berkeley BART. The relatively-more-elaborate facilities at three other locations involving grade changes for passengers - Transbay Terminal, Yerba Buena, and Oakland Airport - also are costed as transit centers. Finally, an allowance is included for 500 parking spaces on each branch (1,500 total), a relatively small number in consideration of the urban and inner-suburban communities the system would serve.

4. Systems

Systems includes the revenue light rail vehicles (LRVs), all of the electrical and mechanical elements of the project that support and/or control their movement, ancillary elements such as fare collection equipment, and the LRV storage and maintenance facility, including shop equipment and non-revenue support vehicles.

- a. Traction Electrification. This system incorporates two major sub-systems: traction power substations and the overhead contact system (OCS).

Substations: Convert high-voltage commercial AC power to DC and step it down to the voltage used by LRVs, typically 750 VDC. Typically, substations are placed at roughly one-mile intervals along the line.

OCS: Consists of the feeder lines, poles, wires and associated fastenings that carry power from the substations to LRVs operating along the line. An OCS featuring only one contact wire above each LRT track, but with underground parallel feeders is envisioned for good aesthetics.

- b. Communications, Signals and Other Electrical. These are the subsystems that facilitate the movement of LRVs over the network, and that ensure operations are safe.

Crossings & Intersections: Protection from cross traffic is provided by either railroad-type gates and flashers, or by prioritized traffic light equipped with special phases and indications for LRVs. Since the at-grade portions of the Transbay system are mostly in public streets, prioritized traffic light will be the predominant type of protection at intersections. Gates and flashers will be limited to a few locations where roads cross LRT on private r-o-w.

Interlockings: Assemblages of control circuitry, signals and switch machines to control track turnouts and crossings, and to ensure the safe movement of LRVs

through such areas. Interlockings are located where such special trackwork is frequently used, or must be able to be used promptly during times of abnormal operation. Such locations are indicated above in Sec. 3D.

Signals: Block signals control following and opposing LRV movements between interlockings on sections of LRT line located on private r-o-w, or that have only a single track. On the Transbay LRT system, signals are provided for the main stem between Transbay Terminal and 40th/San Pablo, and on the outer ends of the airport and Berkeley branches.

Communications: There are two basic communications functions: operational command and control, and passenger information and safety. Sub-systems typically include two-way train radio, on-board public address, and some systems monitoring and control functions relaying status data (e.g., on substations and ticket vending machines) back to Central Control (see below) and commands out to field installations. Less frequently, station closed circuit television monitoring, public address and reader-board displays are provided. Levels of investment in communications vary over a large range for LRT systems, from very basic to fairly extensive.

Duct Bank: This underground facility provides space for running traction power feeder cables (see Sec. 4A) and communications fiber optic transmission systems to connect field locations and Central Control. If more pathways are provided than the LRT system needs, the excess can be rented out to other users and provide a secondary source of revenue.

Central Control: Central Control provides a place for dispatchers and assistants to direct LRV movements over the network, monitor remote installations and initiate corrective actions. For an extensive network such as Transbay LRT, it is useful to have a real-time display showing the locations of all trains, and the positions track switches and, where used, train control signals. Central Control is usually located at the central maintenance facility (see below), and also includes reporting and rest facilities for train operators, and operating management offices.

Other Electrical: Includes costs for OCS pole foundations, wayside lighting systems installed by the LRT project, and miscellaneous other electrical work not specifically identified at present.

- c. Fare Collection. It is assumed that self-service, proof-of-payment ticketing will be used. Passengers will be required to have a valid proof of payment when on board LRVs, subject to random inspection by roving staff who will have the power to issue citations, similar to parking tickets, to fare evaders. Each station platform is assumed to be equipped with two ticket vending machines (TVMs) that, in

addition to accepting cash, should be capable of accepting debit and credit cards as payment for multiple ride tickets and passes.

- d. Light Rail Vehicles and Parts. The LRV fleet is sized based on previously-estimated running times, service on each branch every 15 minutes, and train lengths of two or three LRVs. It is assumed that partial (70%) low floor LRVs similar to those in Portland and New Jersey, and on order for San Jose, will be used. The cost estimate includes procurement of the cars and an initial supply of spare parts. It is noted that an order for 70 (two-car trains) or 105 (three-car trains) should prove attractive to suppliers, and should be sufficiently large to obtain a competitive price.
- e. Maintenance Facilities and Equipment. A central facility will be needed to store and maintain LRVs, and to serve as a base for wayside maintenance forces working primarily on facilities in the field. The facility will need to include a storage yard for LRVs, a shop building in which to service and repair them, a variety of shop tools and equipment (some common to machine shops, some highly specialized). At this stage of project definition, it is only practical to include an allowance per LRV to provide a rough estimate of costs for these items.

In addition, the LRT system will need a variety of mobile equipment for transportation supervisory and wayside maintenance forces, ranging from standard automobiles and light trucks to heavy and highly specialized equipment for maintaining trackage and electrical systems. An allowance per mile of line is included in the estimate to recognize the cost of these items.

5. Other Costs

All projects include so-called "soft costs" for items that are neither construction nor systems procurements, but which are nonetheless an integral and necessary part of completing the work.

- a. Right-of-Way. The Transbay LRT system is envisioned as operating primarily in existing public streets and other public r-o-w. Nonetheless, some land will have to be purchased, including small parcels for substations and other ancillary field installations, some passenger stations, park-n-ride lots, and a fairly large site for the central yard and shop. At about 2.5 LRVs per acre, the latter would be about 28 acres for a 70-LRV fleet, and 42 acres for a 105-LRV fleet.
- b. Contingency. With no engineering or design work actually done, the LRT system is presently defined at only a very conceptual level; and there are undoubtedly many cost elements that have been omitted. To offset that limitation, the contingency allowance is set at a high percentage: 40% of all the previously-specified costs, including Construction, Systems and Right-of-Way.

- c. Management and Engineering. Implementation of a rail system is a major undertaking, involving the work of transportation, community and environmental planners, engineers of many specialties, and project administrators. These costs begin with planning studies; continue through preliminary and final design and environmental documentation; supervision of construction, procurement and installation; and, finally, system testing and start-up. These costs are estimated at 30% of all the preceding costs.

6. Summary of Conceptual Cost Estimates

Estimates for the entire 36.3-mile Transbay LRT system have been prepared assuming the use of either two-car or three-car trains. The shorter trains would provide peak hour peak direction (PHPD) capacity as follows, assuming that each LRV carries 125 passengers.

Location on System	Two-Car Trains	Three-Car Trains
Main Stem (5-Minute Headways)	3,000	4,500
Each Branch (15-Minute Headways)	1,000	1,500

Estimated capital costs for the total system, with either two- or three-car trains, and by major cost category, are as follows. Recognize that these conceptual estimates provide an approximation of the cost to implement the Transbay LRT system. The totals may be considered accurate within a few percentage points, but costs for the individual elements are likely to vary considerably from the estimate. Typically, some items will come in higher, but will be offset by other items that come in lower.

Item	Millions of Dollars		
	Transbay LRT - 36.3 Miles		Eastbay - 28.2 Mi
	Two-Car Trains	Three-Car Trains	Two-Car Trains
Construction	\$ 371	\$ 371	\$ 314
Systems (Wayside)	\$ 212	\$ 212	\$ 169
Revenue Vehicles	\$ 210	\$ 315	\$ 150
Maint. Facilities & Equipment	\$ 48	\$ 67	\$ 37
Right-of-Way	\$ 18	\$ 20	\$ 18
Contingencies	\$ 343	\$ 393	\$ 275
Management & Engineering	\$ 360	\$ 413	\$ 289
Total Estimate	\$1562	\$1791	\$1252
Average Cost per Mile of Line	\$ 43	\$ 49	\$ 34

It is not necessary that the entire Transbay LRT system be implemented all at once. As shown above, an Eastbay-only system would also be a possibility, with connections to The City initially provided by BART, as at present, and adding the Bay Bridge LRT link later.

Other alternatives would be to build the main stem and one at a time, or the main stem and a portion of one or more branches as a "starter" LRT system. One example would be: main stem plus "OA" to Oakland City Hall, and "BT" to Berkeley BART (UC-Berkeley). Other combinations also could be considered in an effort to find the best balance of initial investment and service to customers.

FIGURE 5-2
ALTERNATIVE A - BAY BRIDGE LIGHT RAIL: ESTIMATED LINK MILES & RUNNING TIMES

Route(s)	From	To	Miles	Time	Vavg	Cum Mi	Cum Time
OA,MH,BT	Transbay Tml	Yerba Buena	3.3	6	33.0	3.3	6
OA,MH,BT	Yerba Buena	Oakland Hbr	3.7	6	37.0	7.0	12
OA,MH,BT	Oakland Hbr	40th/San Pablo	1.1	4	16.5	8.1	16
OA	40th/San Pablo	City Hall	1.8	7	15.4	9.9	23
OA	City Hall	E 14th/Oak	0.6	3	12.0	10.5	26
OA	E 14th/Oak	Foothill/Hgnberger	6.0	24	15.0	16.5	50
OA	Foothill/Hgnberger	Coliseum BART	1.8	7	15.4	18.3	57
OA	Coliseum BART	Airport	3.4	13	15.7	21.7	70
MH,BT	40th/San Pablo	MacArthur BART	0.8	3	16.0	8.9	19
MH	MacArthur BART	B'way/MacArthur	0.9	4	13.5	9.8	23
MH	B'way/MacArthur	Mills College	5.5	22	15.0	15.3	45
MH	Mills College	Coliseum BART	2.6	10	15.6	17.9	55
OA	Coliseum BART	Airport	3.4	13	15.7	21.3	68
BT	MacArthur BART	Telegrph/Ashby	2.2	9	14.7	11.1	28
BT	Telegrph/Ashby	Telegrph/Bancroft	0.8	3	16.0	11.9	31
BT	Telegrph/Bancroft	Berkeley BART	0.7	3	14.0	12.6	34
BT	Berkeley BART	University/MLK	0.9	4	13.5	13.5	38
BT	University/MLK	Unvrsty/San Pablo	1.1	5	13.2	14.6	43
BT	Unvrsty/San Pablo	Foot of University	0.9	4	13.5	15.5	47

FIGURE 5-3
PRO-FORMA TIMETABLE FOR ALTERNATIVE A, BAY BRIDGE - EASTBAY LIGHT RAIL SYSTEM

Eastbound (Read Down)												Westbound (Read Up)												
MH	OA	BT	MH	OA	BT	MH	OA	BT	MH	OA	BT	Stations	BT	OA	MH	BT	OA	MH	BT	OA	MH	BT	OA	MH
9.00	9.05	9.10	9.15	9.20	9.25	9.30	9.35	9.40	9.45	9.50	9.55	Transbay	10.04	10.09	10.14	10.19	10.24	10.29	10.34	10.39	10.44	10.49	10.54	10.59
9.16	9.21	9.26	9.31	9.36	9.41	9.46	9.51	9.56	10.01	10.06	10.11	40/San Pablo	9.48	9.53	9.58	10.03	10.08	10.13	10.18	10.23	10.28	10.33	10.38	10.43
9.19	--	9.29	9.34	--	9.44	9.49	--	9.59	10.04	--	10.14	MacArthur BART	9.45	--	9.55	10.00	--	10.10	10.15	--	10.25	10.30	--	10.40
--	9.28	--	--	9.43	--	--	9.58	--	--	10.13	--	City Hall	--	9.46	--	--	10.01	--	--	10.16	--	--	10.31	--
9.45	--	--	10.00	--	--	10.15	--	--	10.30	--	--	Mills College	--	--	9.29	--	--	9.44	--	--	9.59	--	--	10.14
9.55	10.02	--	10.10	10.17	--	10.25	10.32	--	10.40	10.47	--	Coliseum BART	--	9.12	9.19	--	9.27	9.34	--	9.42	9.49	--	9.57	10.04
10.08	10.15	--	10.23	10.30	--	10.38	10.45	--	10.53	11.00	--	Airport	--	8.59	9.06	--	9.14	9.21	--	9.29	9.36	--	9.44	9.51
--	--	9.44	--	--	9.59	--	--	10.14	--	--	10.29	Berkeley BART	9.30	--	--	9.45	--	--	10.00	--	--	10.15	--	--
--	--	9.57	--	--	10.12	--	--	10.27	--	--	10.42	Foot of University	9.17	--	--	9.32	--	--	9.47	--	--	10.02	--	--

FIGURE 5-4
ALTERNATIVE A – LIGHT RAIL TRANSIT: CAPITAL COST ESTIMATE – UNIT COSTS

Cost Element	Unit Cost	Description of Cost Basis/Rationale
CIVIL CONSTRUCTION: ▶ Utility Relocation ▶ Civil/Roadway ▶ Aerial Structures: · Bay Bridge · Other Structures	\$500/SRF* \$500/SRF* \$1,000/Lin Ft \$5,000/Lin Ft	▶ Allowance per route foot (lin ft) considering LRT in urban arterial streets with little-to-moderate work on underground utilities likely. ▶ Addition of LRT within existing urban street with some street work, but does not include complete reconstruction of street. ▶ Allowance for special LRT work outside general bridge rehab/rebuild. ▶ LACMTA Long Beach Blue Line LRT project. * SRF = Surface Rt Ft = Lin Ft (Linear Feet) at Grade.
TRACKWORK: ▶ Open Track ▶ Embedded Track ▶ Special Trackwork	\$175/Trk Ft \$400/Trk Ft \$75k Each	▶ Portland Westside LRT; tie and ballast, direct fixation. ▶ Portland City Streetcar, shallow trench w/booted rails in concrete. ▶ Portland Westside LRT, track switches & diamonds.
STATIONS: ▶ Surface Stations ▶ Bus Transit Centers ▶ Surface Parking	\$500k Each \$3 mil Each \$2,700 per Space	▶ Portland Westside LRT. LRT stations only; excludes bus transit centers and automobile park-ride lots. ▶ Tri-Met FOG report. ▶ Comparable recent projects.
ELECTRIFICATION: ▶ Substations ▶ O'head Contact Sys	\$500k Each \$100/Track Ft	▶ Portland Westside LRT; average 1 per mile. ▶ Portland Westside LRT; poles, supports, wires.

FIGURE 5-4 (CONT.)
ALTERNATIVE A – LIGHT RAIL TRANSIT: CAPITAL COST ESTIMATE – UNIT COSTS

Cost Element	Unit Cost	Description of Cost Basis/Rationale
COMMO & SIGNALS: ▶ Crossings & Intersections ▶ Interlockings ▶ Signals/TWC ▶ Communications	\$150,000 Each \$90/Rt Ft \$80/Rt Ft \$525k Each	▶ Portland Westside LRT; gates/flashers <u>or</u> special traffic lights. ▶ Portland Westside LRT; see text for locations & descriptions. ▶ Portland Westside LRT; signals-bridge & interlockings, TWC throughout. ▶ Portland Westside LRT and other recent LTK projects.
SYSTEMS ELECTRICAL: ▶ Duct Bank ▶ Central Control ▶ Other Electrical	\$80/Rt Ft \$5 Million \$1,500k/Rt Mi	▶ Portland Westside LRT. ▶ Portland Westside LRT & similar projects. ▶ Portland Westside LRT; pole foundations, lighting, other electrical.
FARE COLLECTION: ▶ Tkt Vending Machines	\$75k Each	▶ Portland & other recent projects; 4 TVMs/station, 8 TVMs/transit center.
YARD & SHOP: ▶ LRV Yard, Maint Shop & Equip ▶ Support Vehicles	\$550k/LRV \$250k/Line Mi	▶ Portland Westside LRT. ▶ Portland Westside LRT.
REVENUE VEHICLES: ▶ Vehicles & Spare Parts	\$3 mil Each	▶ Recent low floor LRV orders.
OTHER COSTS: ▶ Right-of-Way, main line ▶ Right-of-Way, yard & shop ▶ Contingency ▶ Engineering & Management	\$500k/Line Mi \$125k/acre 40% 30%	▶ Land for substations, transit centers, park-rides. ▶ Yard & shop facility sized at 2.5 LRVs per acre. ▶ Need high contingency due "0%" design. ▶ Portland Westside LRT & similar projects.

BART TRANSBAY BRIDGE SERVICE

BART capital costs are significantly influenced by civil and structural design, and on the particularities of a specific alignment, whether at-grade (lowest cost), aerial, or in subway (highest cost). No engineering has been done for this option. Therefore, the illustrative capital cost figure here is based on average per-mile costs for "comparable" BART projects elsewhere.

For this purpose, use is made of recent estimates for the Fremont - San Jose/Santa Clara extension, prepared as part of the MTC "Bay Area Transportation Blueprint for the 21st Century." Costs for that project are provided in the "Project Notebook of Candidate Projects," dated October 1999, with costs quoted in 1999 dollars.

The Project Notebook provides capital costs for extension in three segments:

Segment	Capital Cost Estimate	Length	Average Cost per Mile
Fremont - Warm Springs	\$553 million	4.6 miles	\$120 million
Warm Springs - Tasman	\$750 million	6.9 miles	\$109 million
Tasman - Santa Clara	\$2.75 billion	9.5 miles	\$289 million
Total	\$4.045 billion	21 miles	\$193 million

It is assumed that these costs include stations and rolling stock.

Note that the average cost per mile for the segment south of Tasman is more than twice the average of the segments to the north. This is due to the high average cost of subway construction, in this case under Santa Clara Street through Downtown San Jose. For purpose of the development of illustrative capital cost estimation for the BART Bay Bridge alternative, the \$120 million cost per mile of the Fremont - Warm Springs extension will be used here. It is assumed that the BART alignment will not involve subway construction, other than the Yerba Buena Island Tunnel and station. The tunnel itself is included in the structural cost estimate for the Bridge rail modification; the station may be considered as included in the above averages.

The most obvious potentially difficult structural elements of this alternative, assuming a rail-ready Bridge is made available, are the initial segment from the MacArthur station junction, rising to the south and turning west into the median of the I-580 freeway. Much of the freeway itself is on structure, and real estate acquisition may be required. Difficult structure may also be required at the San Francisco end to bring the line down from the Bridge into the Transbay Terminal, presumably into a two-track stub terminal on the upper level. No structural engineering for this alternative has been done in any of these areas, so the capital cost provided here, even with the 40% contingency, must be considered conjectural.

If \$120 million per mile is assumed as an average for MacArthur - Transbay Terminal, 8.9 miles, plus a 40% contingency, and 30% for engineering and project management, consistent with the estimates for the other alternatives, an illustrative order of magnitude capital cost may be calculated as follows:

$$1.3 \text{ engineering and management}[(8.9 \text{ miles})(\$120 \text{ million per mile})(1.4 \text{ contingency})] =$$

\$1.943 billion

BASIC BRIDGE RAILROAD PASSENGER SERVICE

Infrastructure

The following table summarizes the main cost categories for both the Basic and Aggressive railroad alternatives. In this table, the totals in the Aggressive column are incremental, and must be added to the Basic column to reach the totals in the "Total all Services" column.

Rolling Stock Summary

As discussed above, the cost is based on 27 married-pair EMUs at \$4.5 million each, plus one Acela set at \$22 million, totaling \$143.5 million, rounded to \$144 million. Acela sets are shown as "Intercity" in the cost table.

Capacity Estimate

Estimated capacity delivered across the Bridge would be four 10-car EMU trains per hour plus two Acela trains per hour, per direction, or a delivered capacity (using capacity figures from Working Paper 2A.2), of:

$$4 (10)(150) + 2 (304) = 6608 \text{ passengers per peak hour per direction.}$$

FIGURE 5-5
TRANSBAY SERVICE INVESTMENT COST SUMMARY

INVESTMENT CATEGORY	BASIC SERVICE		AGGRESSIVE SERVICE		TOTAL BASIC	TOTAL AGGRESSIVE	TOTAL ALL SERVICES
	San Francisco to Richmond	Oakland Harbor to Jack London Square	Richmond to Sacramento	Jack London Square to San Jose			
Right-of-Way, Demolition, Utility Relocation	\$17.4	\$7.1	\$50.0	\$66.6	\$24.5	\$116.6	\$141.1
Grading	\$6.1	\$1.2	\$79.3	\$15.5	\$7.3	\$94.8	\$102.1
Track Work	\$36.5	\$5.9	\$38.0	\$47.1	\$42.4	\$85.1	\$127.5
Structures	\$28.4	\$45.0	\$186.3	\$542.7	\$73.4	\$729.0	\$802.4
Train Control and Grade Crossing Warning Devices	\$22.9	\$8.8	\$47.6	\$51.0	\$31.7	\$98.6	\$130.3
Electrification	\$72.8	\$15.9	\$214.9	\$91.5	\$88.7	\$306.4	\$395.1
Other	\$0.0	\$7.5	\$12.0	\$8.5	\$7.5	\$20.5	\$28.0
Stations	\$15.0	\$1.5	\$40.0	\$19.0	\$16.5	\$59.0	\$75.5
TOTAL, CONSTRUCTION BEFORE PROFIT	\$199.1	\$92.9	\$668.1	\$841.9	\$292.0	\$1,510.0	\$1,802.0
Contractor Profit	\$19.9	\$9.3	\$66.8	\$84.2	\$29.2	\$151.0	\$180.2
Purchase of Former WP				\$91.2		\$91.2	\$91.2
TOTAL RIGHT-OF-WAY SPECIFIC COSTS	\$219.0	\$102.2	\$734.9	\$1,017.3	\$321.2	\$1,752.2	\$2,073.4
Other Non Right-of-Way Specific							
Wayside Communications							\$5.0
Dispatching Modifications							\$2.0
Shop for Commuter Equipment					\$39.7	\$40.6	\$80.3
Rollings Stock							
EMUs					\$121.5	\$229.5	\$351.0
Intercity Equipment					\$22.0	\$88.0	\$110.0
TOTAL, ALL INVESTMENT BEFORE CONTINGENCY AND ENGINEERING					\$504.4	\$2,110.3	\$2,621.7
ENGINEERING (30%)					\$151.3	\$633.1	\$786.5
CONTINGENCY (40%)					\$262.3	\$1,097.4	\$1,363.3
TOTAL					\$918.0	\$3,840.7	\$4,771.5

AGGRESSIVE BRIDGE RAILROAD PASSENGER SERVICE

Infrastructure

The itemized cost elements for the Aggressive alternative are shown in the table above.

FIGURE 5-6
ROLLING STOCK SUMMARY

Service	Round Trip Running Time*	Peak Headway	Peak Trainsets Required
"A" Commuter	180 minutes	30 minutes	6 EMU sets
"B" Commuter	210 minutes	30 minutes	7 EMU sets
Capitol Corridor	300 minutes	60 minutes	5 Acela sets

* Running time is San Francisco (Transbay Terminal) to outer terminal, per Working Paper 3A.1, x2, plus assumed layover time at outer terminal.

Thirteen EMU sets, assuming all are 10-car trains, would represent 130 cars, or 65 married pairs. Providing for 20% spares, this would mean 78 married pairs @ \$4.5 million per pair, this would represent a cost of \$351 million.

Five Acela sets at an estimated \$22 million each, for two power cars and six trailers per set, would represent a cost of \$110 million.

Acela sets are shown as "Intercity" in the cost table.

Total rolling stock cost: \$461 million.

Capacity Estimate

Estimated capacity delivered across the Bridge would be four 10-car EMU trains per hour plus two Acela trains per hour, per direction, or a delivered capacity (using capacity figures from Working Paper 2A.2), of:

$$4(10)(150) + 2(304) = 6608 \text{ passengers per peak hour per direction.}$$

CHAPTER 6. CONCLUSIONS AND NEXT STEPS

This feasibility level analysis was designed to identify possible transbay rail options and to determine whether any of these options is feasible from a structural engineering perspective, based on their impact on the Bay Bridge. The study was limited to the retrofitted west spans and the proposed replacement East spans of the Bay Bridge. The four rail technologies included in the study were light rail, BART, commuter rail and high speed rail.

The study concluded that it is feasible to incorporate any of the rail technologies on the Bay Bridge, but at very high cost. The high cost of putting rail on the Bay Bridge is primarily the result of adding live and dead weight to the West spans, which are being retrofitted, but not replaced under the current plan. Adding a significant amount of weight to that structure would almost certainly require seismic and structural strengthening work on the foundations and the main cable, even if a lighter decking material were to be implemented. The cost for structural improvements to the configuration studied in this analysis could be as high as \$3 Billion, with significant additional investment required for rail infrastructure, rolling stock and operations.

This feasibility level study was not intended as a substitute for a full corridor study. As the demand for transbay travel increases, additional capacity and additional alternatives to the private auto will be needed. BART's Transbay tube will soon reach capacity, and transbay buses, mixing with vehicular traffic for at least a portion of their route, may not be able to compete for the market share that could otherwise be gained by transit. While the cost of adding rail to the bridge is high, the cost of doing nothing may be higher, in terms of hours of delay, impact on the region's economic vitality and quality of life.

To determine the true costs and benefits of this potential rail crossing, other opportunities for transbay transit services must be considered. The next step would be a full multi-modal corridor study that could compare the benefits of putting rail on the Bay Bridge to other potential transbay transit projects. These could include a busway, a second bridge (either a rail bridge or auto bridge, relieving the need to retain full roadway capacity on the Bay Bridge itself), or a new submerged tube for rail service. Any of these alternatives appear to be feasible and workable with the underground rail terminal in the basement of the Transbay Terminal.

MTC has committed to completing a Bay Crossing Study that would further the analysis done in this feasibility study and would provide the information necessary to compare this potential investment against investments in other modes or rail options. MTC will be studying a number of new Transbay crossing options including:

- Additional or expanded auto bridges, with or without rail service
- An rail tube under the Bay

- A second BART tube
- A rail tube connecting Oakland and San Francisco airports
- Expanded ferry service
- Expanded bus service and busway options

If after a feasibility level study of the other options, rail on the Bay Bridge remains competitive, a more detailed study of the bridge structures is required. This more detailed study would not complete significant engineering, but would help to better understand the improvements needed and the costs of construction.

A sample workplan would include:

- Adopt an optimal location for vehicles and rail on the bridge to develop a more detailed structural assessment and cost assessment.
- Assess the feasibility highway operations impacts of placing rail on the deck of the existing structure and placing additional vehicle lanes on either side or below the structure. While this option appears to be structurally feasible, no highway operations assessment has been completed.
- Develop a more detailed understanding of the life cycle implications of alternative decking materials, including newer light weight technologies that are not currently used by Caltrans.
- Finalize selection of the train system and set operational speeds over the bridge given the alignment geometry and the service and seismic movements of the bridge.
- Develop three-dimensional computer models of the East and West spans and the Yerba Buena Tunnel. Include the proposed structural modifications for adding rail to determine the structural integrity and the need for additional seismic improvements if this work is completed.
- Complete both service and seismic analysis and design for the selected rail and deck scenario.
- Define required realignments of roadway ramps and alignment of rail into San Francisco and through the Oakland Mole, and include costs of ramp changes in the overall cost estimate.
- Prepare a refined cost estimate.

APPENDIX A. DEFINITIONS AND NAMING CONVENTIONS

Live load and dead load are terms used widely within the discussion of structures. In general terms, dead load is any weight the structure must support that is unchanging. The bulk of the dead load is the self-weight of the structure and permanent fixtures on the bridge such as roadway wearing surface, sidewalks, guide railing, railroad track, utilities, signing, and signals.

Live loads are considered the weights the bridge must support which are not fixed. Live loads are the weights of cars, trucks, trains, pedestrians, and bicycles.

Two general types of loading are referenced in discussion of bridges; service and seismic loads. Service loads are the common loads the bridge will carry. For the Bay Bridges, these include live, dead, wind, tidal flow, vehicle braking, vehicle centrifugal and maintenance. Seismic loads are a combination of dead load, a percentage of the live load and lateral and vertical acceleration loads due to seismic ground motion.

Later in this paper there are references to “demand” and “capacity” of the bridge as a whole and for individual structural elements. Demand is the seismic or service load that is placed on the bridge or structural element. Capacity is the load the bridge or structural element is capable of carrying at a designated stress level. The capacity load is usually considered to be the maximum design load. A simple example is occupancy of an elevator. With only one person in the elevator, the demand load is one person. However, the placard in the elevator may state that a maximum of 8 people is permitted. In this case the capacity of the elevator is 8 people.

Certain names and references are specific to transportation structures and suspension bridges. Figures 2 through 5 provide the naming convention for the main structural elements of the West spans.

FIGURE A-1
PARTIAL THREE-DIMENSIONAL MODEL –
BAY BRIDGE WEST SPANS

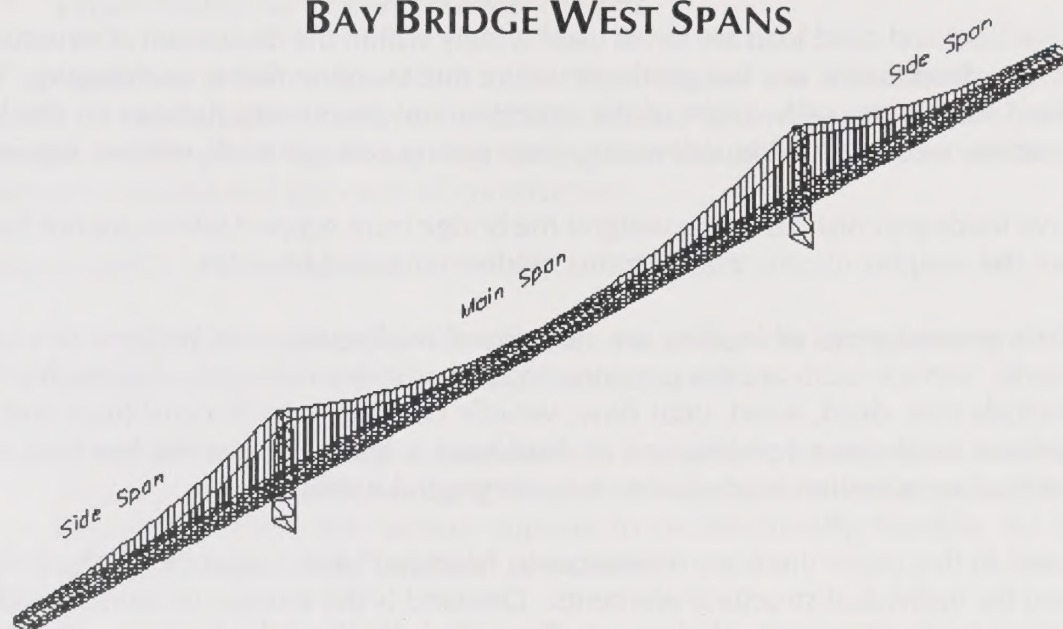


FIGURE A-2
WEST SPANS PARTIAL ELEVATION

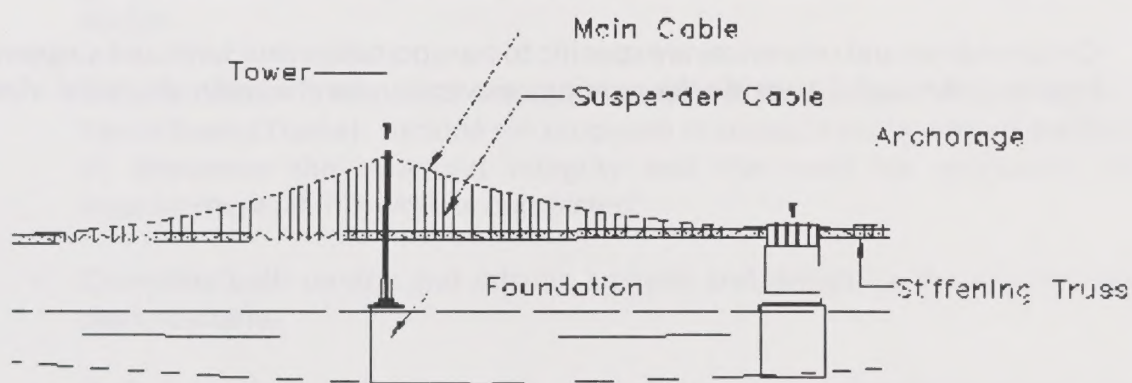


FIGURE A-3
STIFFENING TRUSS – TYPICAL SECTION – SUSPENSION SPANS

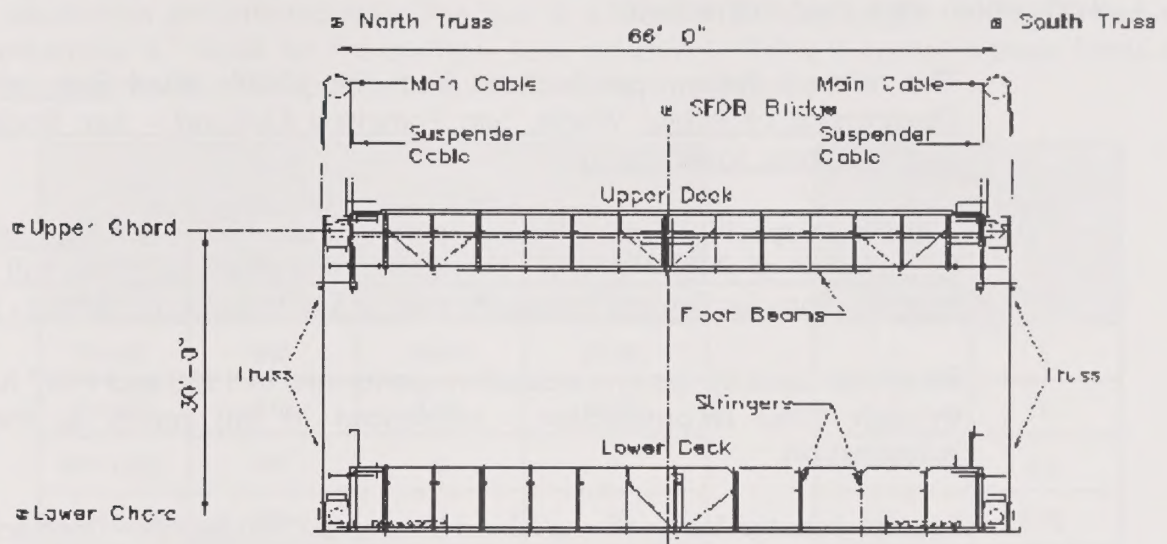
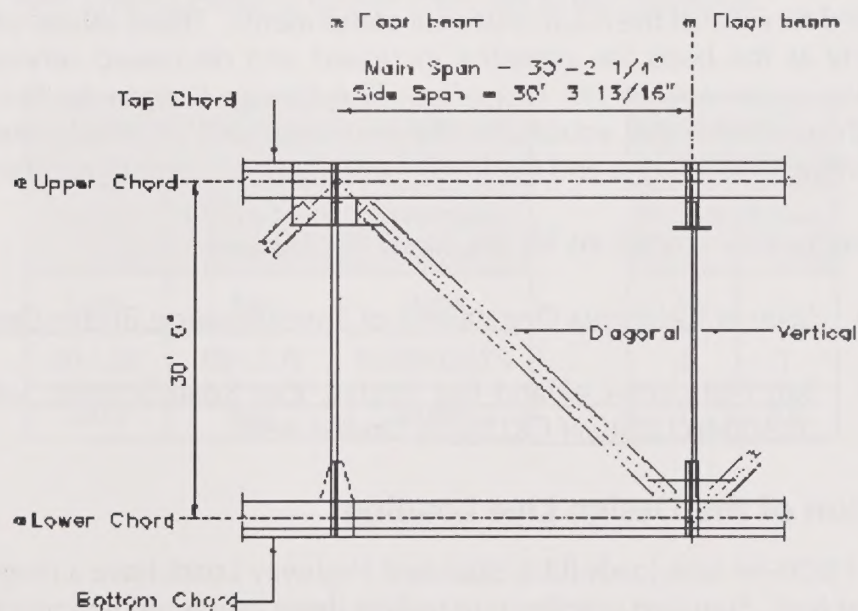


FIGURE A-4
STIFFENING TRUSS – ELEVATION



APPENDIX B. DATA/SPECIFICATIONS

The following is a select list of documents found in the Caltrans' archives or within ongoing work which were used in this study:

- The original design specifications from the 1930's titled State of California Department of Public Works, San Francisco Oakland - Bay Bridge, Design Specifications, Superstructure
- The design specification for the rail removal from 1957 titled State of California Department of Public Works, Division of San Francisco Bay toll Crossings, Specifications for Design, Reconstruction of San Francisco Oakland - Bay Bridge
- Structural capacity design calculations performed in 1965 and 1967 for the 1959 through 1963 reconstruction - referenced in this report as the 1965/67 Investigation.
- Excerpt from the Yerba Buena Island Structural Calculations - Contract #4029
- San Francisco-Oakland Bay Bridge, East Span Seismic Safety Project, contract 59A0040 DESIGN CRITERIA Draft 4-9-99

The 1965 and 1967 calculations are the most complete source of final design information. Within this work the loads and allowable stresses are defined and the demand stresses are calculated for most of the main structural components. These values will be used throughout this study as the basis for assessing increased and decreased service load demands and capacities under various rail scenarios. The Design Criteria for the East Spans is a very thorough document that establishes the live loads and allowable stresses. Comparison of loads within these criteria and the loads from the proposed rail addition will be undertaken.

The governing specifications for this feasibility study are:

- State of California Department of Transportation Bridge Design Specifications
- San Francisco-Oakland Bay Bridge, East Span Seismic Safety Project, Contract 59A0040 DESIGN CRITERIA Draft 4-9-99

Evolution of the Design Live Loading

Typical HS20-44 lane loads (U.S. Standard Highway Load) have a magnitude of 640 pounds per linear foot. Standard practice is to reduce these values recognizing that each lane will not be loaded from end to end or not all lanes will be loaded side by side with the maximum truck weights. Similarly, the cross-lane 'C' factor is a load reduction factor that acknowledges the improbability of full size trucks in each of the three or more lanes simultaneously.

In the 1930's specifications, these reductions were dictated in the design specifications. By the time the 1959 work started, the paper "Live Loadings for Long-Span Highway Bridges" by J.R. Ivy et al appeared in the ASCE Proceeding Vol. 79 dated June 1953. This article set down the parameters and intensities for live load as a function of span length. AASHTO had also introduced a 'C' factor for the multiple lane structures. Table 1 contains those loads and factors, which were incorporated into the 1965/67 Investigation.

Vehicular HS-20 Lane Loads – 1959 (per lane)			
Loaded Length (ft)	Uniform Load (lbs/ft)	Concentrated Moment (lbs)	Load for Shear (lbs)
15-600	640	18,000	26,000
601-800	640	9,000	13,000
801-1,000	640	0	0
1,001-1,200	600	0	0
1,201+	560	0	0

Cross Lane Loading Distribution Factors	
# Lanes	Factor
1	1
2	1
3	0.9
4	0.75
5	0.75

Today, the West spans would be designed to criteria similar to that currently employed on the Proposed East Span Design. Those long span live load intensity values are shown in Table 2. For spans similar to the West spans of the Bay Bridge, the changes between the 1953 ASCE paper and the 1999 criteria create a further decrease in the live loads.

Vehicular HS-20 Lane Loads – 1999		
Loaded (ft)	Uniform Load (lbs/ft)	Concentrated Load (lbs)
0-600	640	18,000
601-1,200	800-L/3.75	32,500 10.833 * L
1201+	640	19,500

Cross Lane Distribution	
# Lanes	Factor
1	1
2	1
3	0.9

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